Development of the Large-Area Picosecond Photo-Detectors

Andrey Elagin
University of Chicago

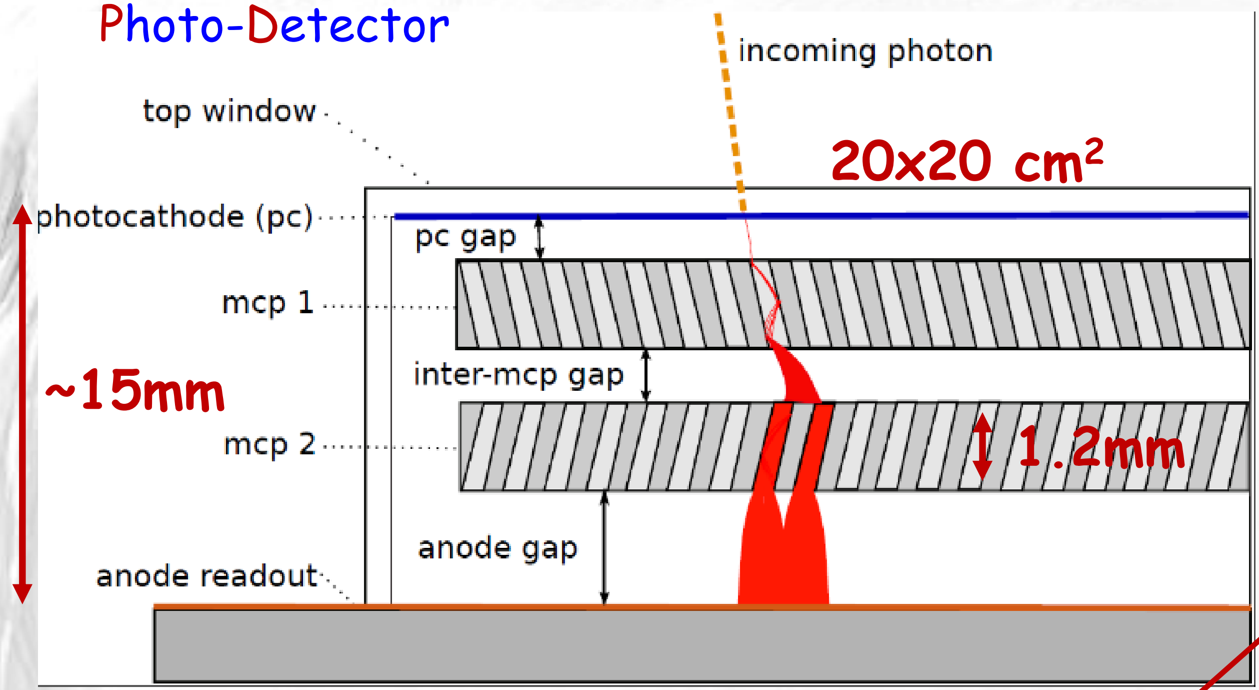
3rd Berkeley Workshop on the Direct Detection of Dark Matter
LBL, December 6, 2016

Outline

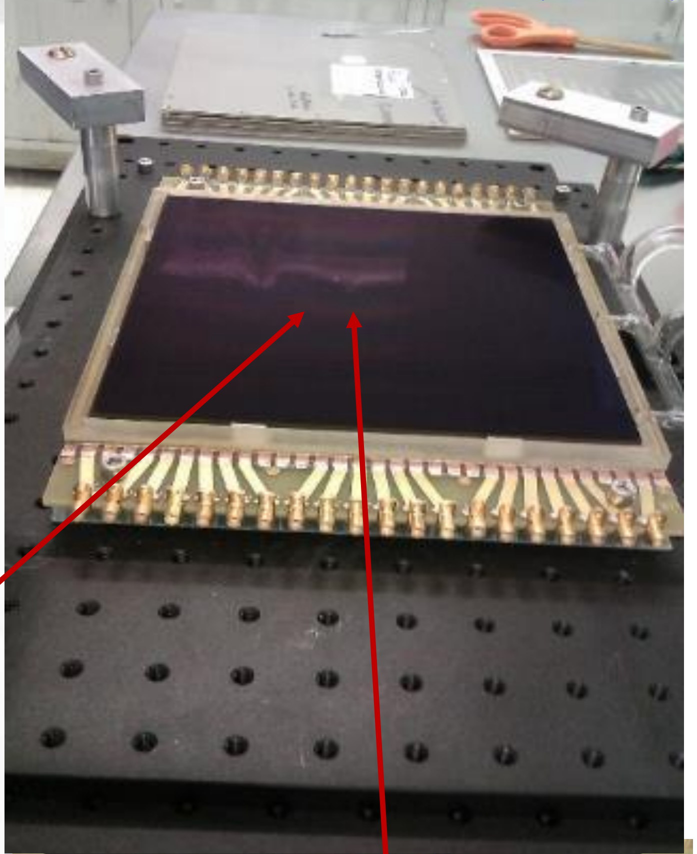
- LAPPD Overview
- Commercialization status at Incom Inc.
- R&D Towards Volume Production
  - development of in-situ assembly process at UChicago
  - Gen-II LAPPD

LAPPD

Large-Area Picosecond Photo-Detector



Micro-Channel Plates (MCPs)

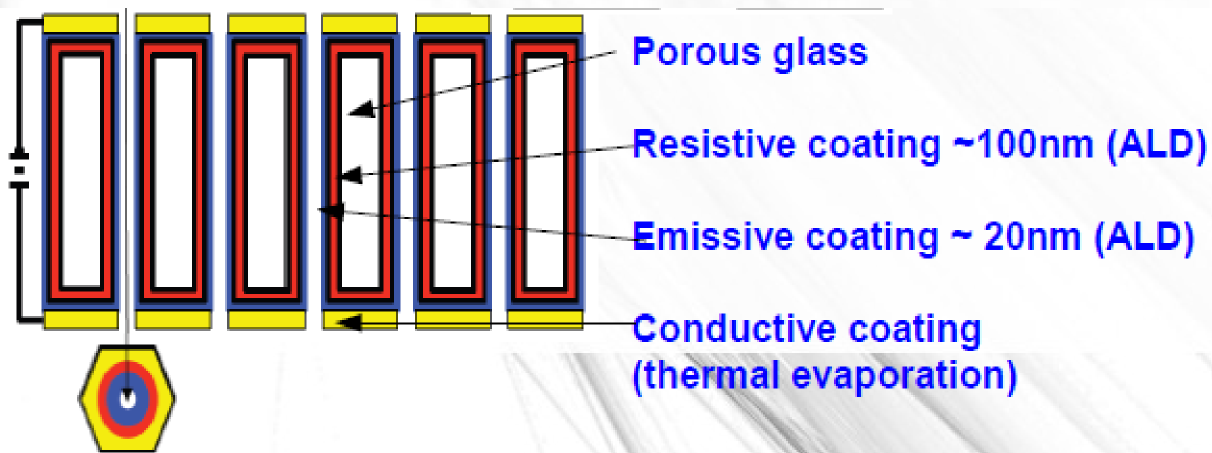


Micro-Capillary Arrays by Incom Inc.

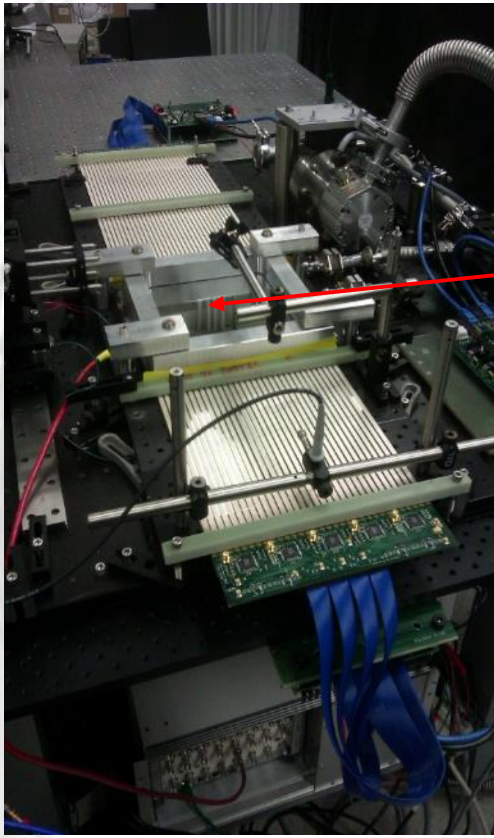
- Material: borofloat glass
- Area: 8x8"
- Thickness: 1.2mm
- Pore size: 20 μm
- Open area: 60-80%

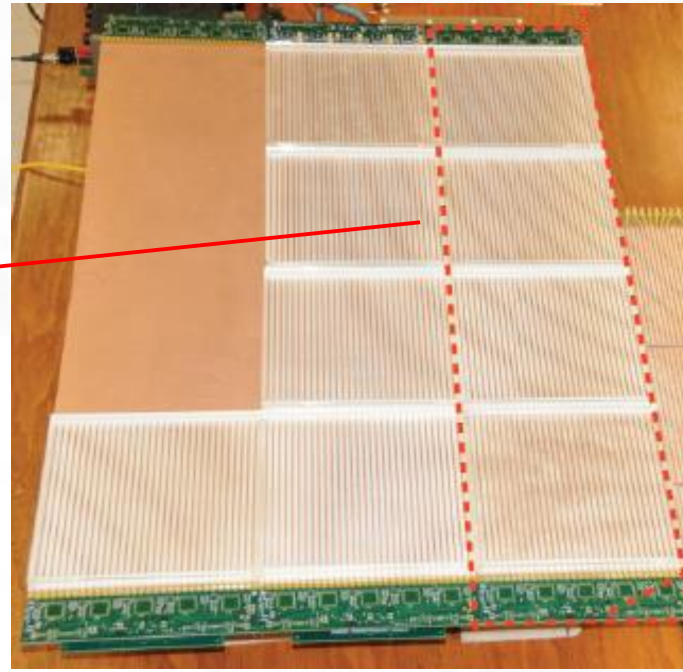
Atomic Layer Deposition (ALD)

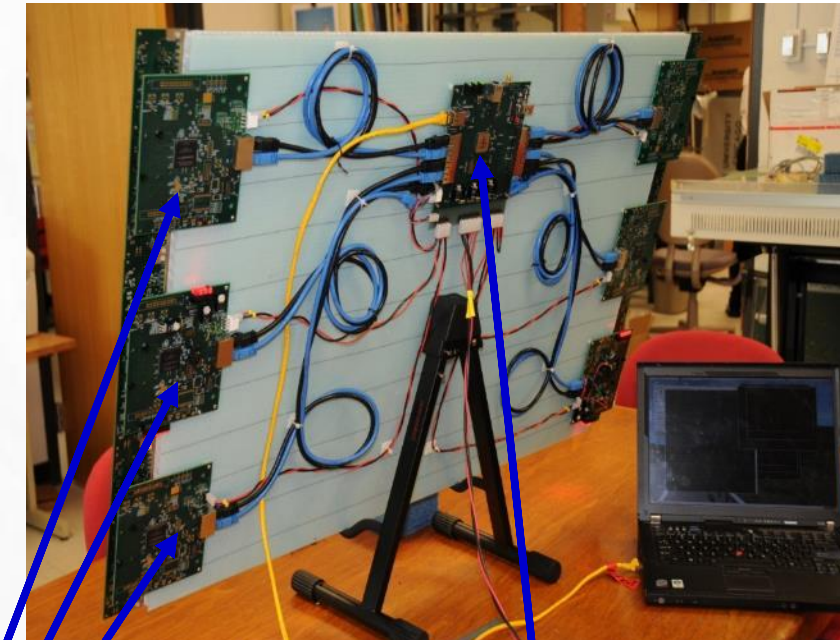
- J.Elam and A.Mane at Argonne (process is now licensed to Incom Inc.)
- Arradiance Inc. (independent process)



LAPPD Electronics







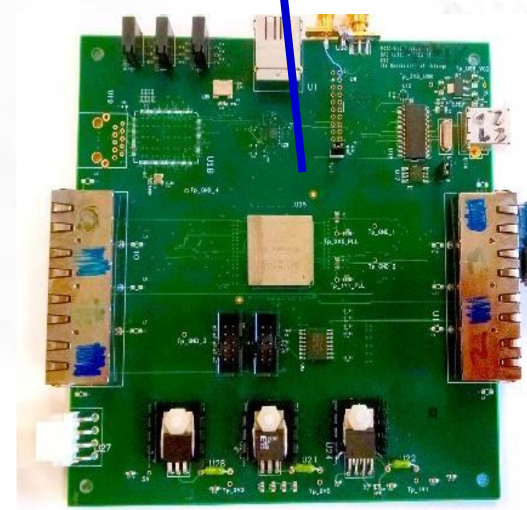
NIM 711 (2013) 124

Delay-line anode
- 1.6 GHz bandwidth
- number of channels scales linearly with area

NIM 735 (2014) 452

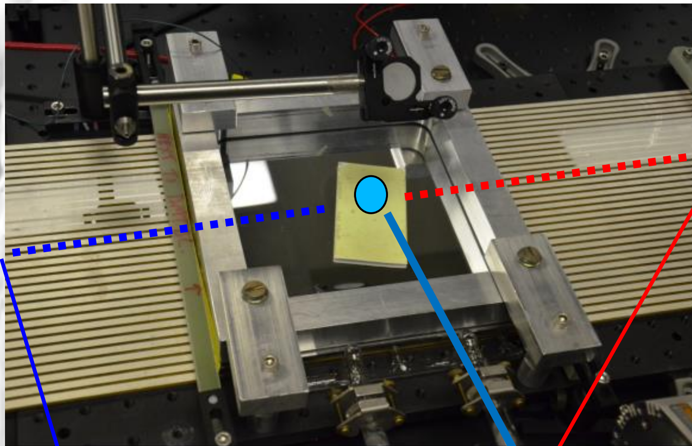
PSEC-4 ASIC chip
- 6-channel, 1.5 GHz, 10-15 GS/s

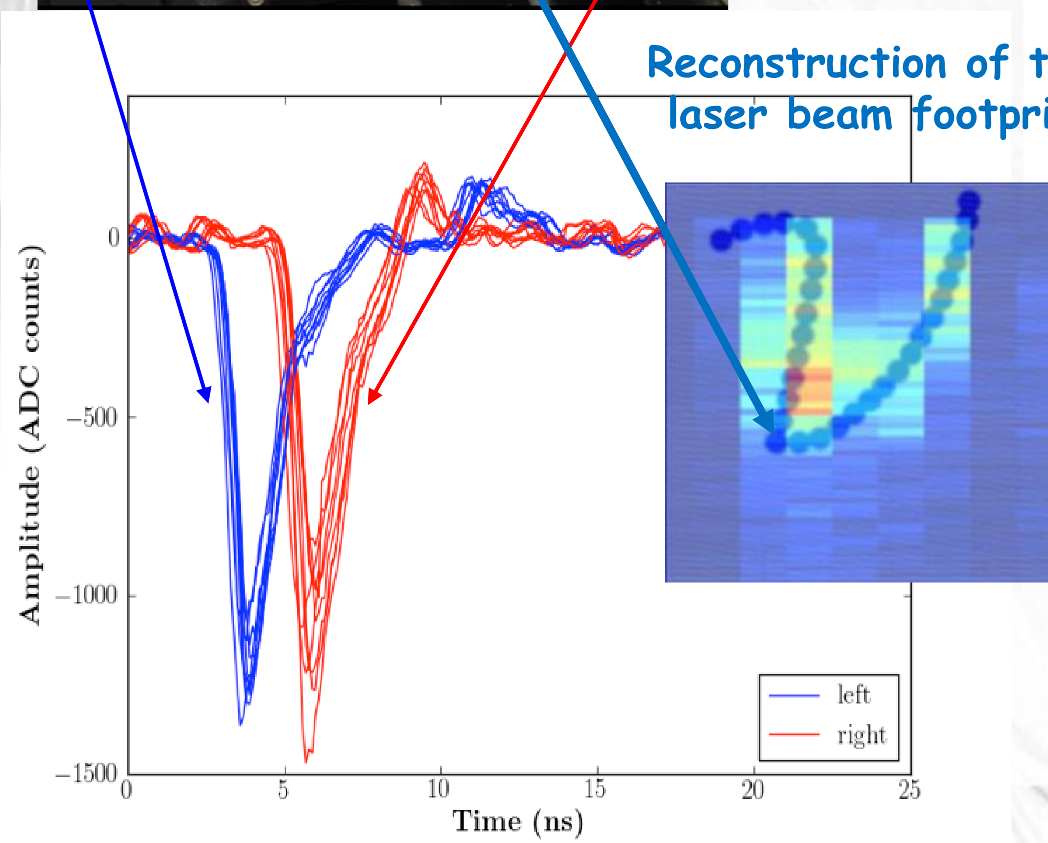
30-Channel ACDC Card (5 PSEC-4)



Central Card (4-ACDC;120ch)

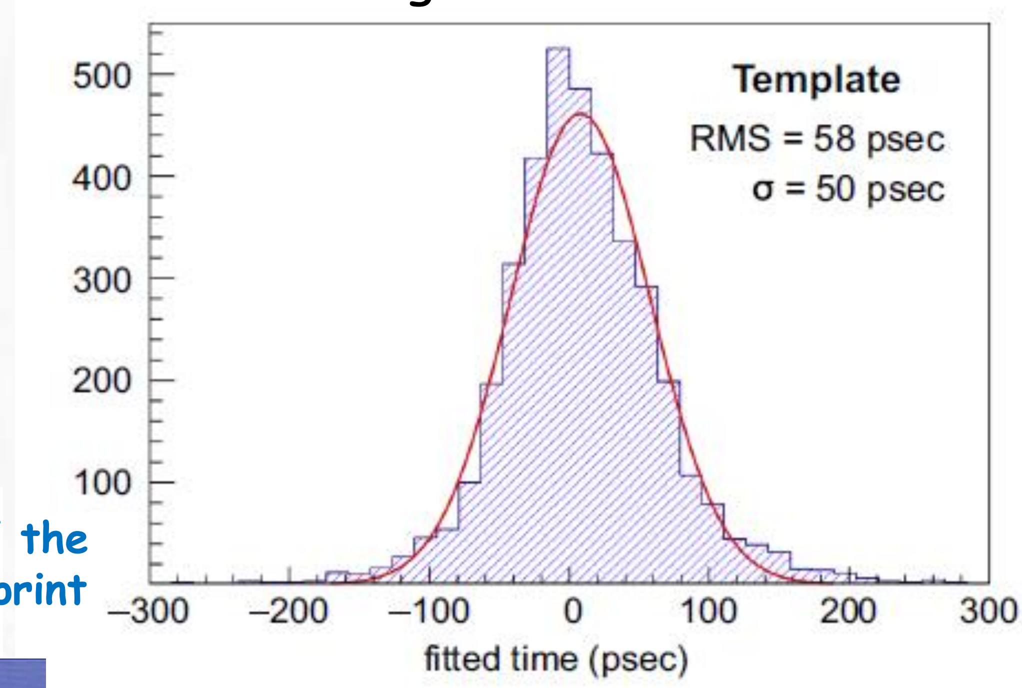
LAPPD Prototype Testing Results





Reconstruction of the laser beam footprint

Single PE resolution



Demonstrated characteristics:

single PE timing ~50ps

multi PE timing ~35 ps

differential timing ~5 ps

position resolution < 1 mm

gain >10^7

RSI 84, 061301 (2013),
NIMA 732, (2013) 392
NIMA 795, (2015) 1

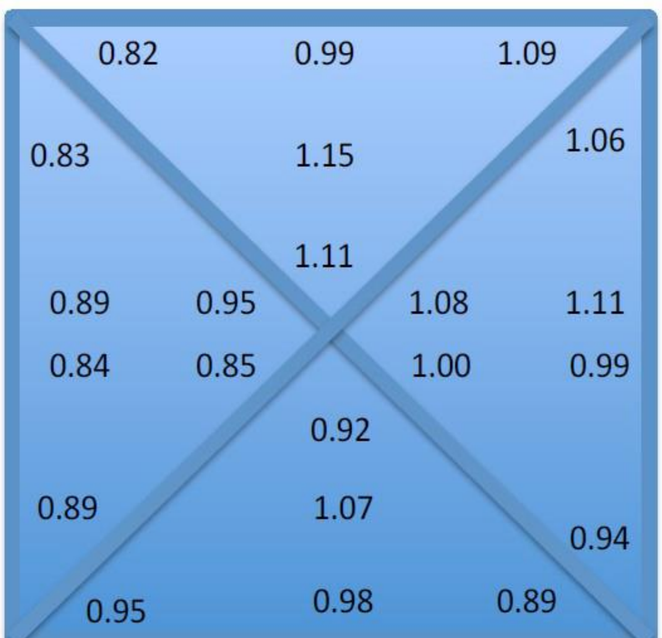
See arXiv:1603.01843 for a complete LAPPD bibliography

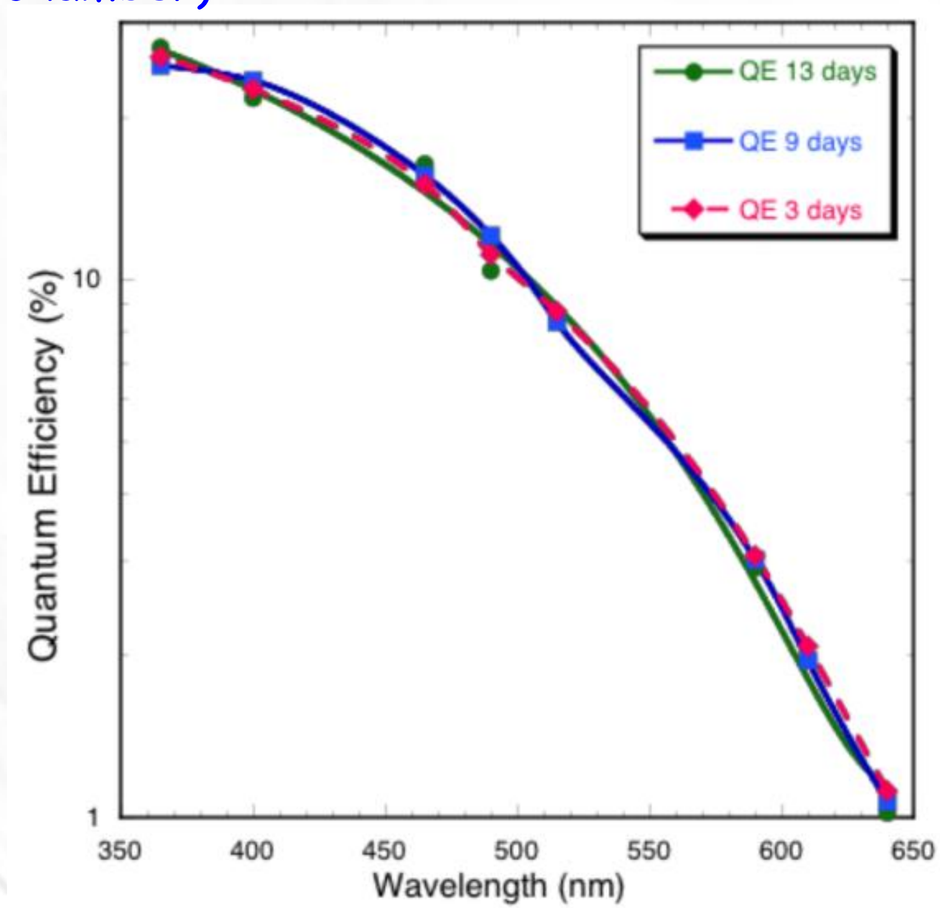
LAPPD Sealing Attempt @ SSL Berkeley

A fully processed ceramic LAPPD tile was tested while still in the vacuum chamber

- Peak QE ~25%
- QE non-uniformity +/-15% over 20x20 cm^2 area
- No change in QE after 2 weeks
- TTS ~ 200 ps (FWHM, using 80ps laser and ad-hoc connectors to get signal out of the vacuum chamber)

QE uniformity map





2014 JINST 9 C04002

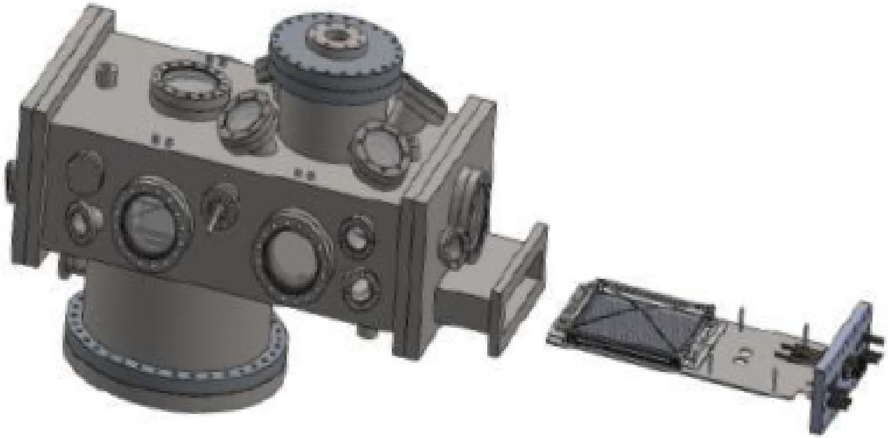
Commercialization Status

- April 2014 - DOE funding to create infrastructure and demonstrate a pathway towards pilot production
- November 2015 – Facility operational
- December 2015 – Commissioning trial initiated
- October 2016 – First Sealed Tile with Bialkali Photocathode
- Now transitioning from "commissioning" to "exploitation" stage

LAPPD™ @ Incom Inc.

Incom V2.0 LAPPD Integration & Sealing

Process & Hardware



Process:

- UHV - with Conflat seals, scroll, turbo and ion pump.
- Tile kit components pre-assembled & locked in place .
- Baked to low 10^{-10} torr range
- In-tank operation of tile / scrubbing
- Window Transfer Process
- Multi-alkali Photocathode deposited on underside of window.
- Hot Indium Seal - with grooved sidewalls

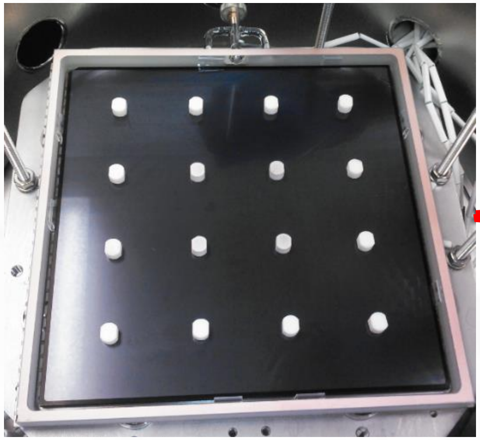
Hardware:

- Single "Fully Bakeable" Chamber: 30"L X 16"W X 8"H
- Simple window transfer between photocathode deposition & sealing.
- Electrical interconnects for in-process monitoring
- Readily expandable for volume production

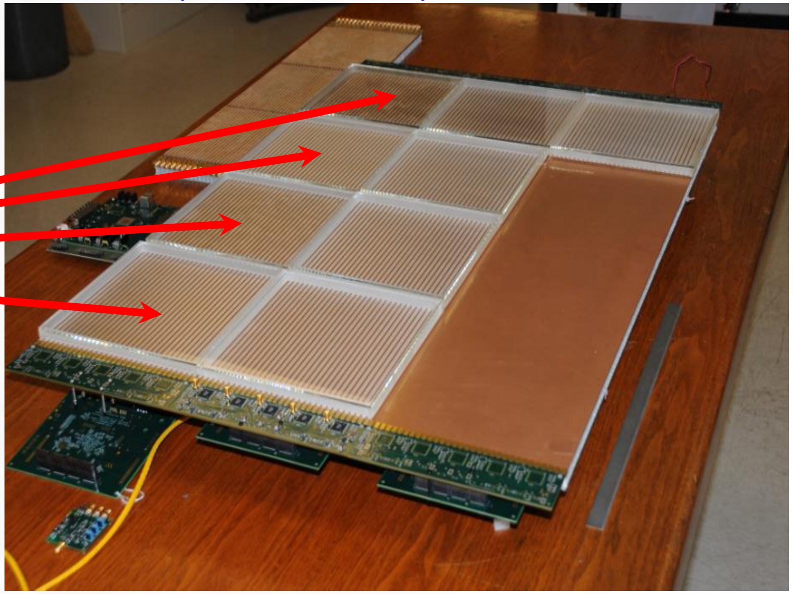
Goal of the R&D Effort at UChicago

Affordable large-area many-pixel photo-detector systems with picosecond time resolution

LAPPD module 20x20 cm^2



Example of a Super Module



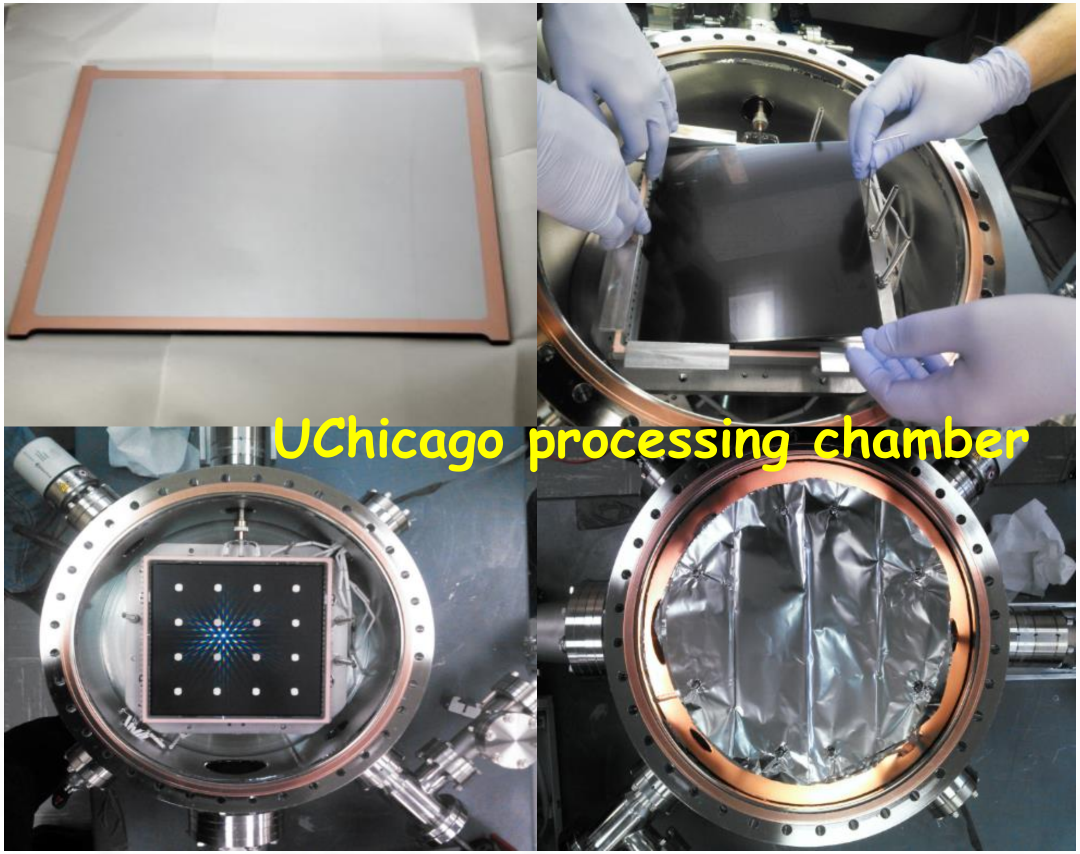
A production rate of 50 LAPPDs/week would cover 100m^2 in one year

- High volume production can be challenging
- We are exploring if a non-vacuum transfer process can be inexpensive and easier for a very high volume production

UChicago goal is to enable high volume production at Incom so we can do physics using LAPPD™

In-Situ Assembly Strategy

Simplify the assembly process by avoiding vacuum transfer:
make photo-cathode after the top seal
(PMT-like batch production)



Step 1: pre-deposit Sb on the top window prior to assembly
Step 2: pre-assemble MCP stack in the tile-base
Step 3: **do top seal and bake in the same heat cycle using dual vacuum system**
Step 4: bring alkali vapors inside the tile to make photo-cathode
Step 5: flame seal the glass tube or crimp the copper tube

In-Situ Assembly Facility UChicago

The idea is to achieve volume production by operating many small-size vacuum processing chambers at the same time

Heat only the tile not the vacuum vessel

Intended for parallelization

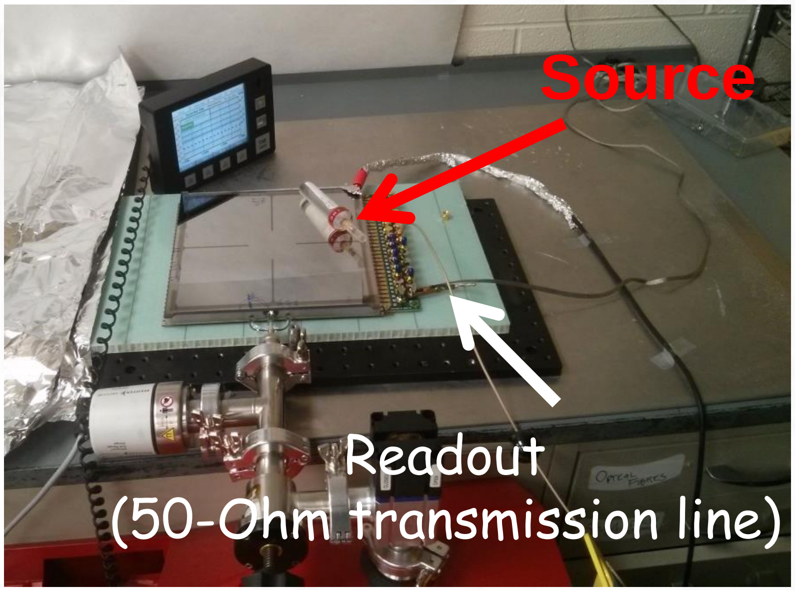
Looking forward towards transferring the in-situ process to industry

First Signals from an In-Situ LAPPD

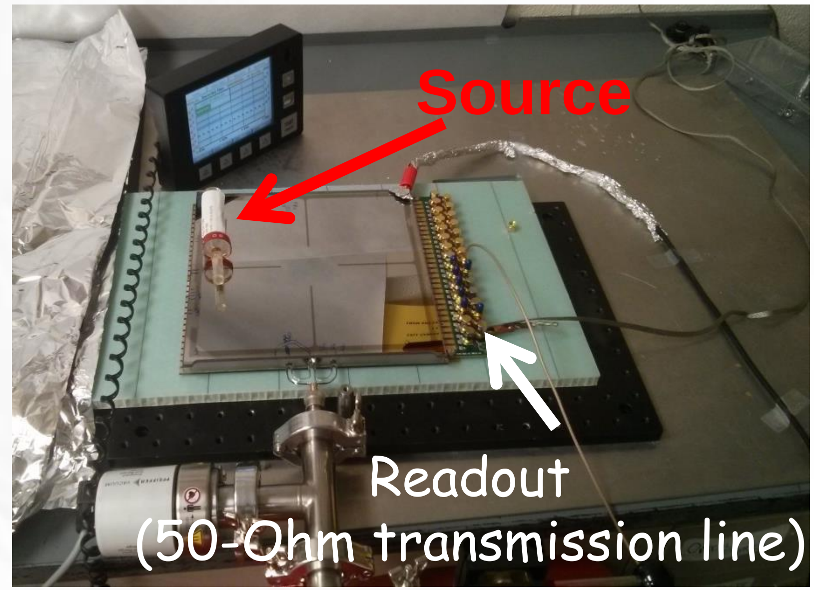
April, 2016

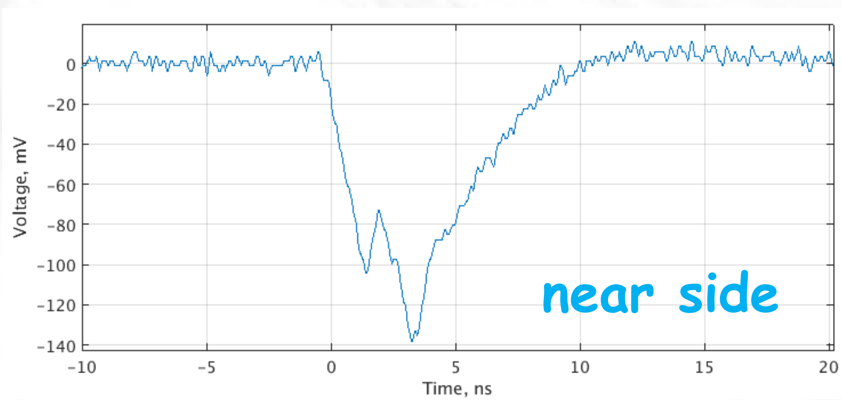
(Sb cathode)

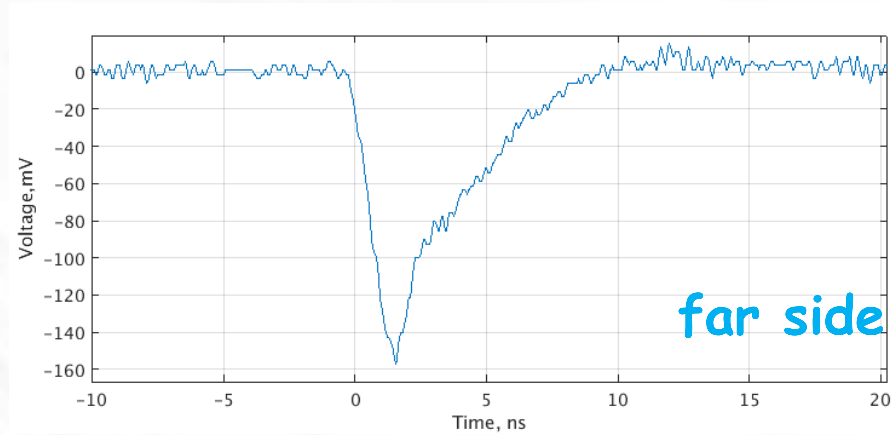
Near side: reflection from unterminated far end



Far side: reflection is superimposed on prompt





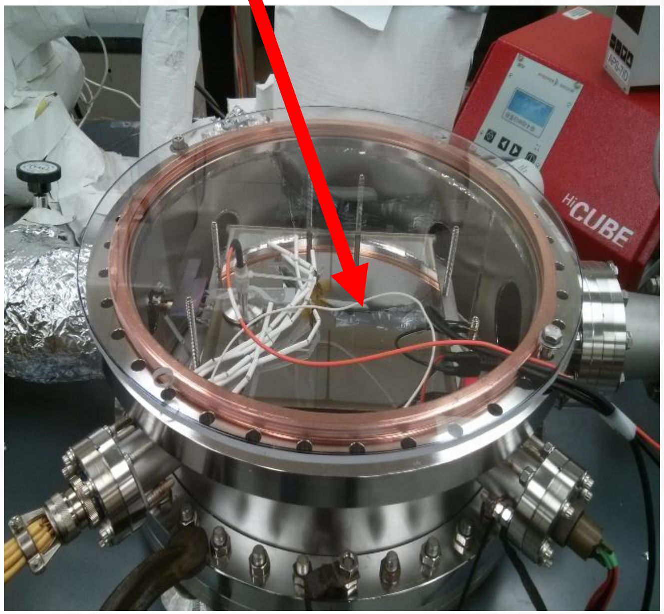


The tile is accessible for QC before photo-cathode shot
Could help the production yield

1st In-Situ Photo-Cathode

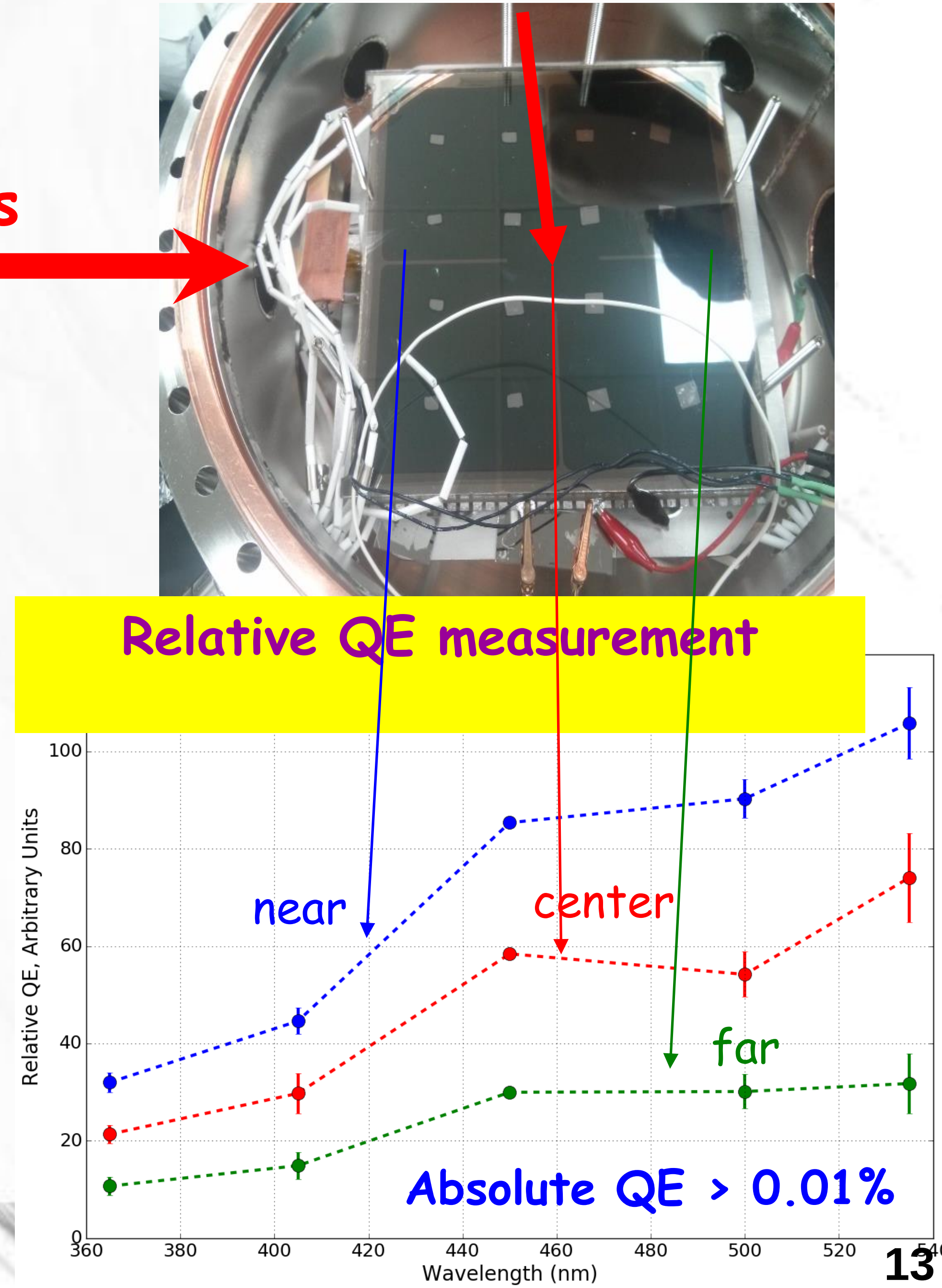
July, 2016

Sb layer only



Cs

Cs-Sb photo-cathode



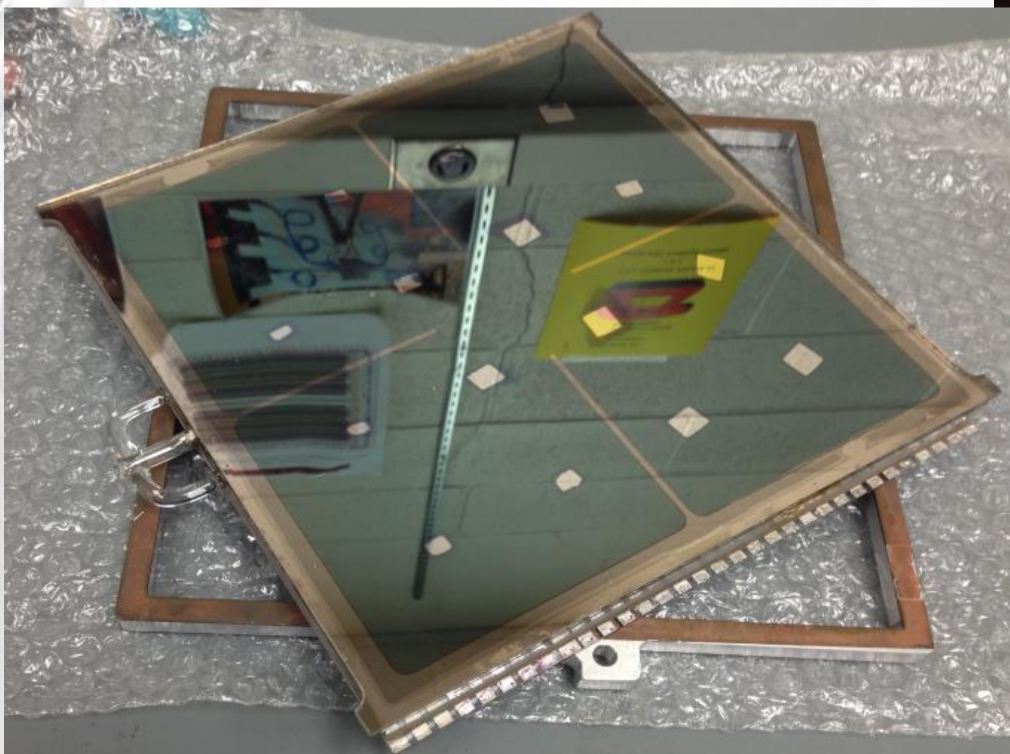
First in-situ commissioning run

- saw first photo-current response from in-situ photo-cathode
- measured relative QE (absolute QE is tricky due to DC current through the whole stack)
- demonstrated a <u>sealed tile</u> configuration
  - no QE drop for 2 weeks after the valve to the pump was closed
  - no QE drop for 3 weeks after flame seal

Note on this commissioning run:
PC is very thick for transmission mode operation
(initial 20nm of Sb translates into ~80nm of Cs-Sb)

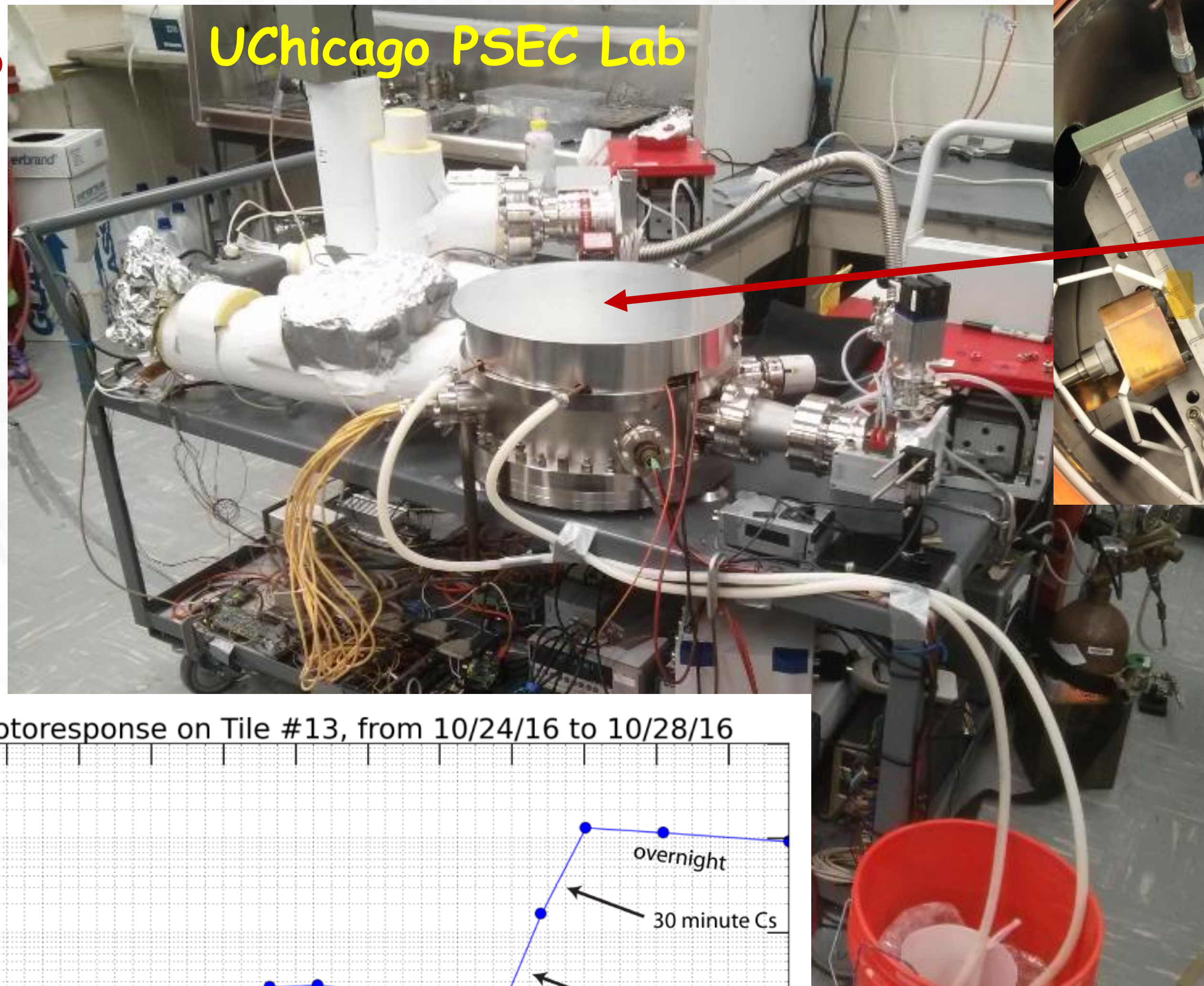
Flame Seal

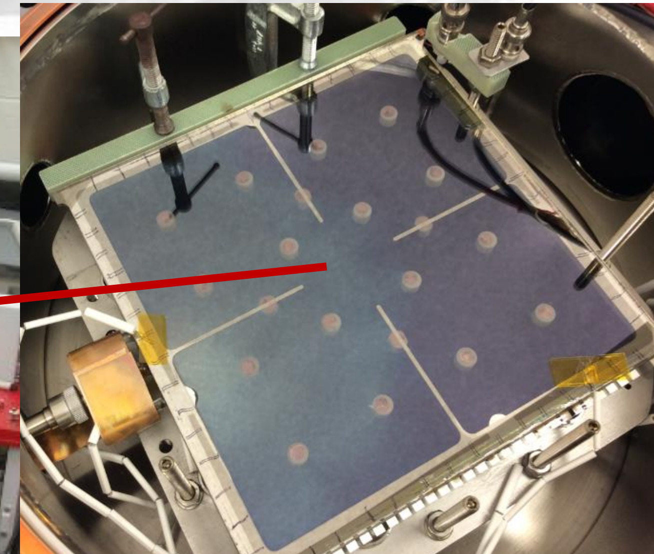
August 18, 2016

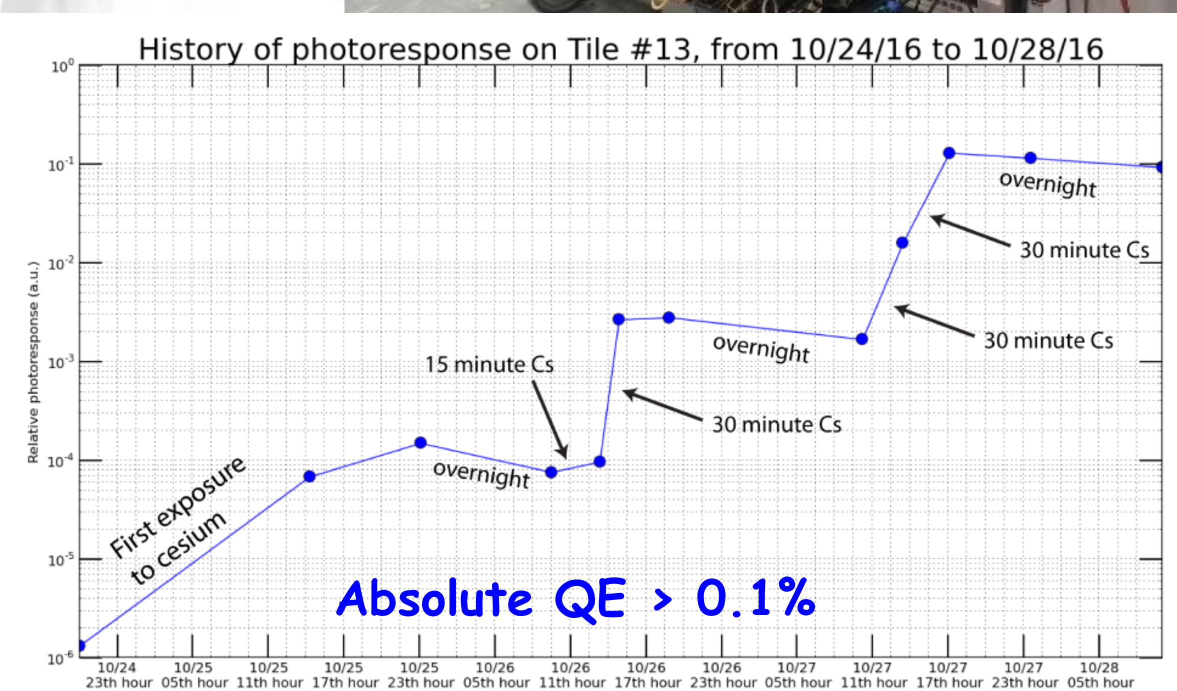


2^{nd} In-Situ Photo-Cathode

Oct - Nov, 2016



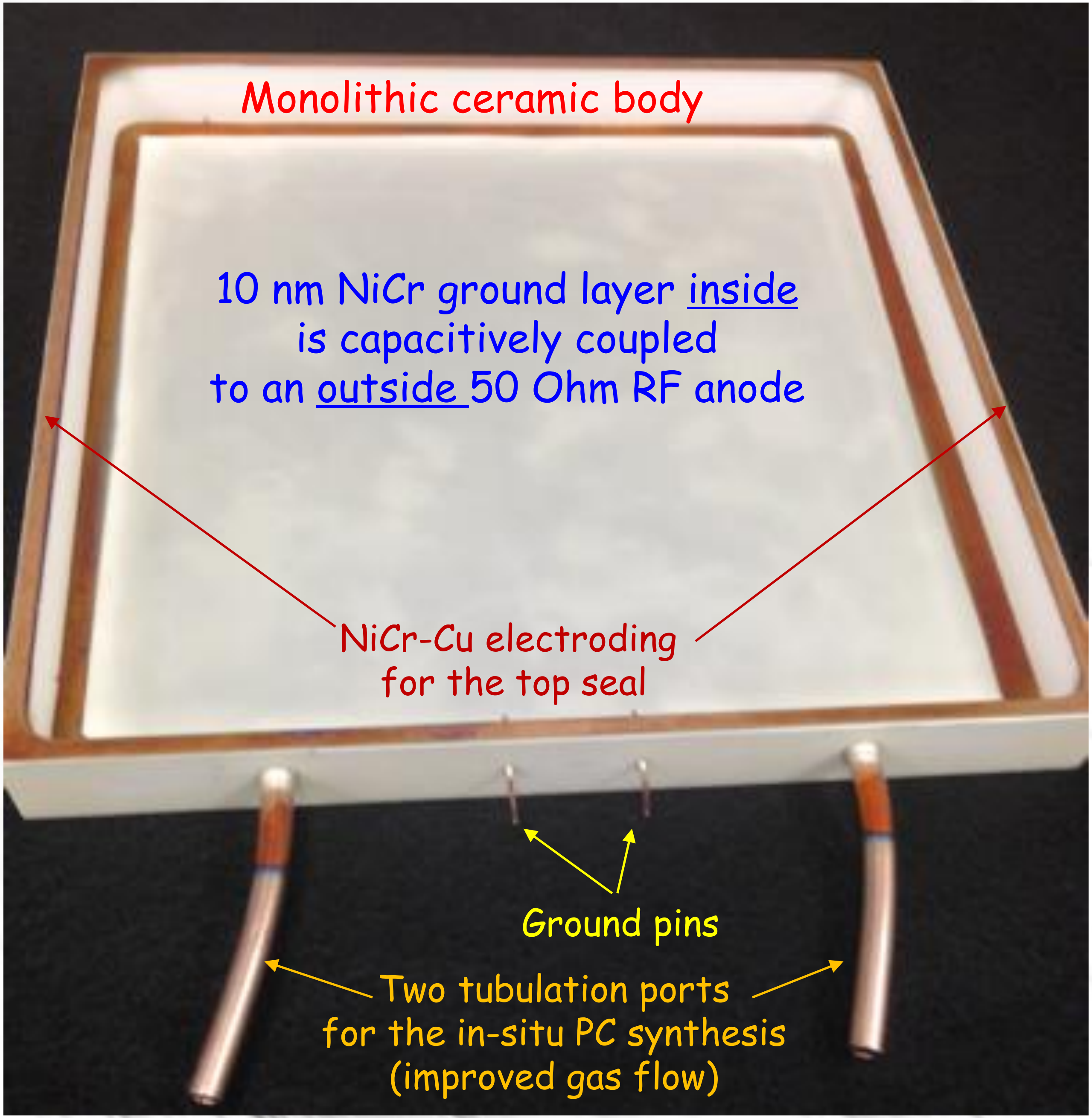




- Thinner Sb layer (~10nm)
- Improved instrumentation and process control
- A factor of 10 improvement in QE
- Currently doing life-time testing (flame sealed on Nov 16)

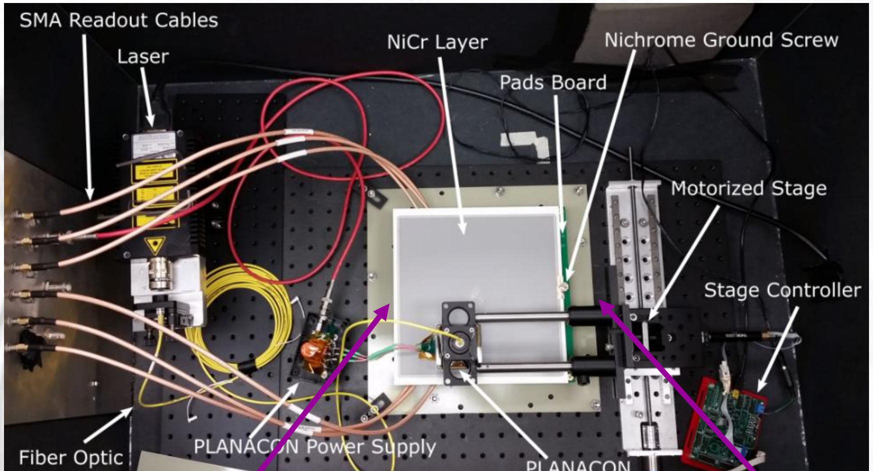
Gen-II LAPPD

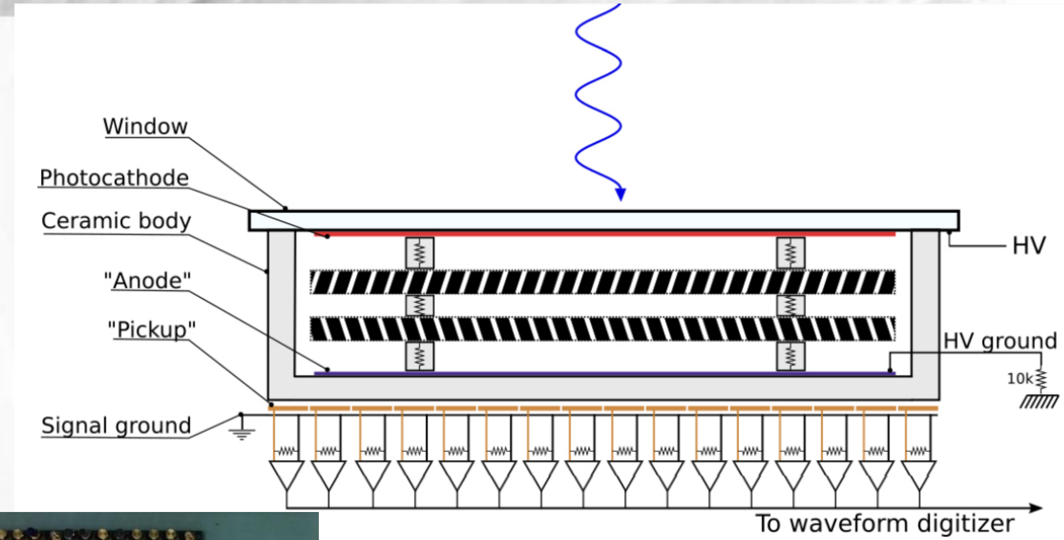
- Robust ceramic body
- Fused silica window
- Anode is not a part of the vacuum package
- Enables fabrication of a generic tile for different applications
- Compatible with in-situ and vacuum transfer assembly processes

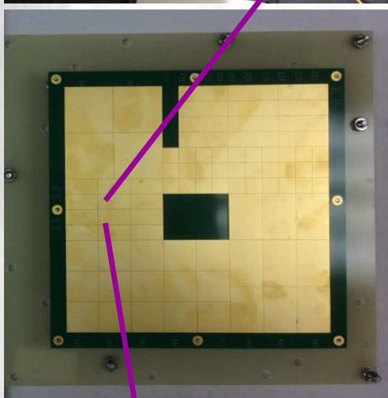


Joint effort with Incom Inc. via DOE NP SBIR Phase-I

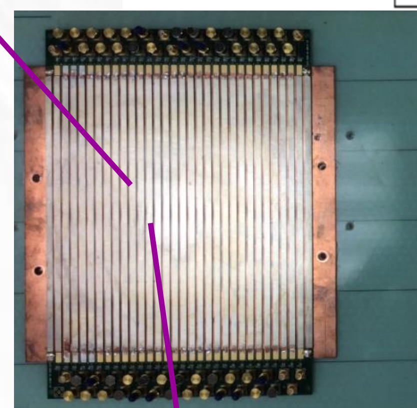
Gen-II LAPPD: "inside-out" anode



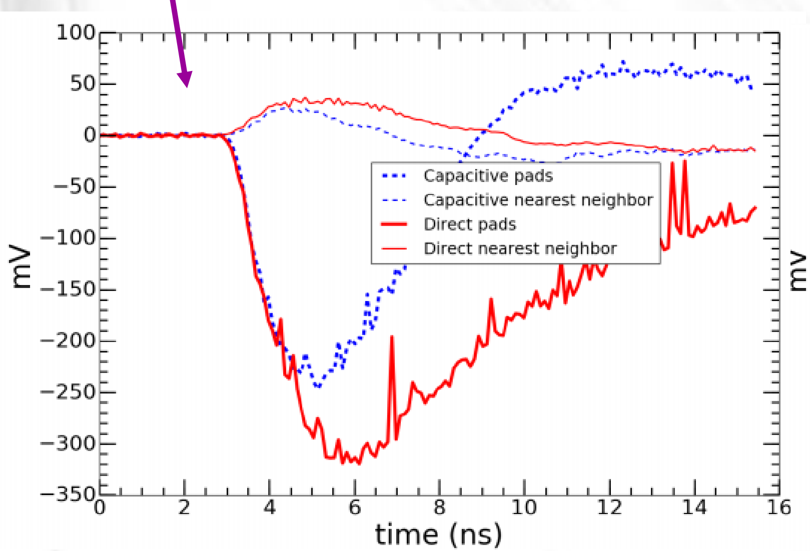


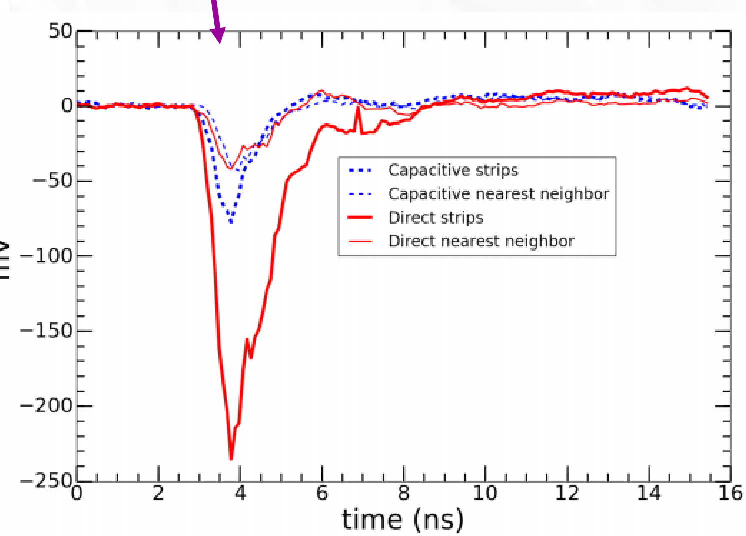


Chose your own readout pattern



- Custom anode is outside
- Capacitively coupled
- Compatible with high rate applications

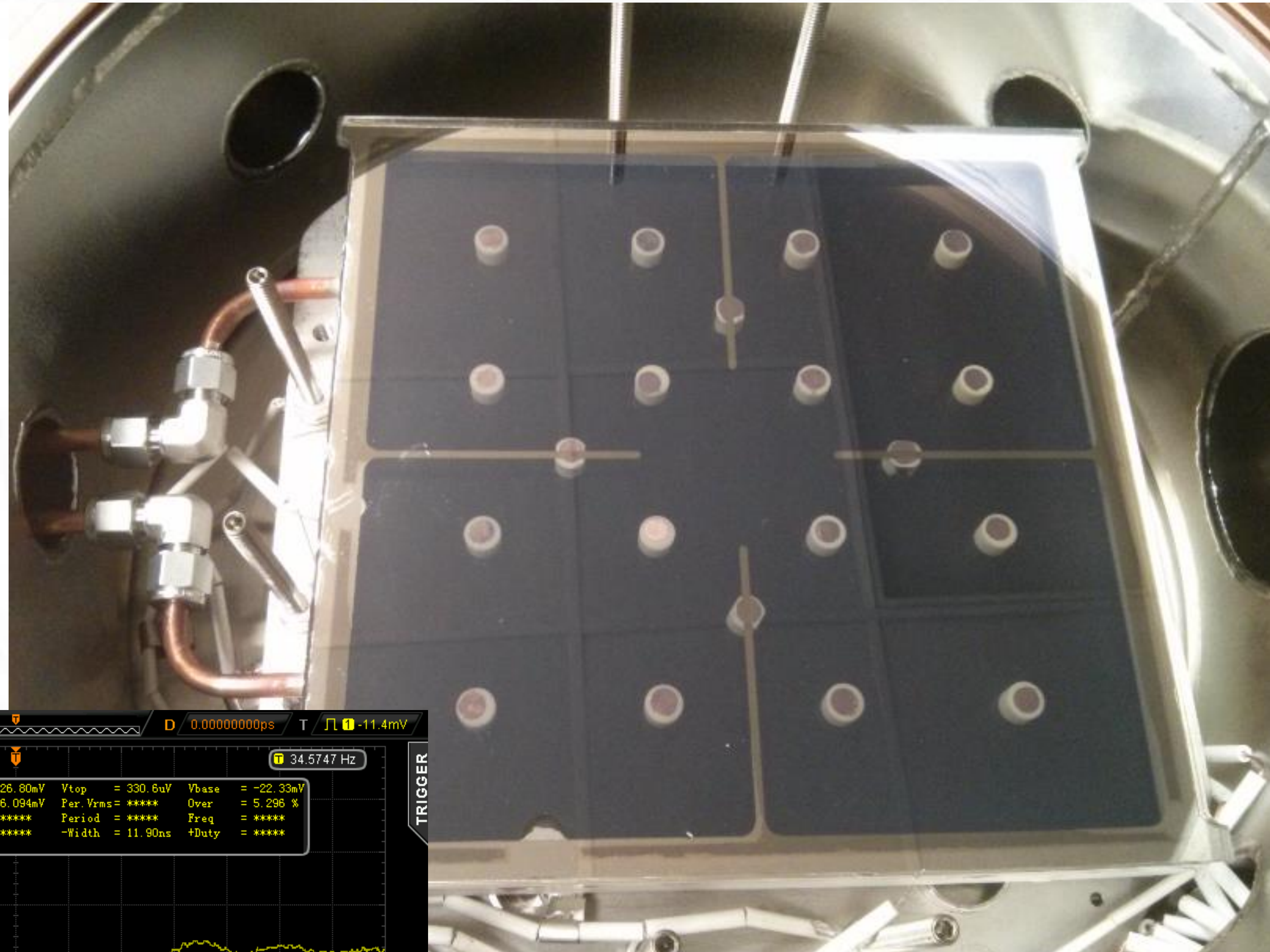


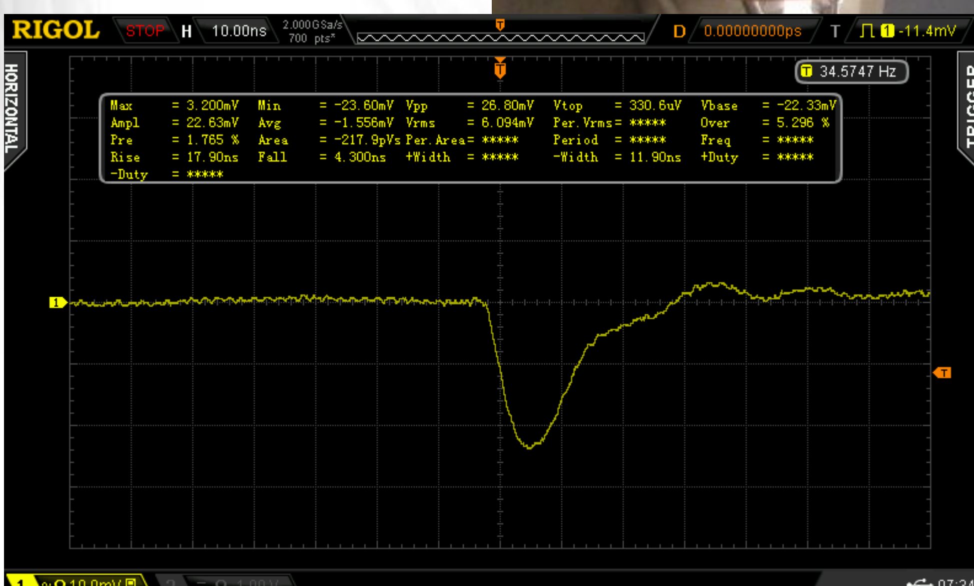


For details see arXiv:1610.01434 (accepted to NIM)

Gen-II LAPPD: work in progress

December, 2016





Summary

- Commercialization at Incom Inc. goes well
  - recently demonstrated first sealed functional LAPPD with bi-alkali photo-cathode
  - transitioning from “commissioning” to “exploitation” stage
- With the goal to use LAPPDs in large experiments UChicago group is focused on R&D for high volume production process
- Making photo-cathode in-situ as a final step is very attractive
  - leak check before PC-synthesis
  - real-time tuning and optimization of PC is possible
- Right at the moment UC group is working on photo-cathode optimization and Gen-II LAPPD vacuum packaging
  - moving towards K_2CsSb photo-cathode trials
  - building 2nd vacuum processing chamber -> parallelization

Back-up

Early Adopters of LAPPD

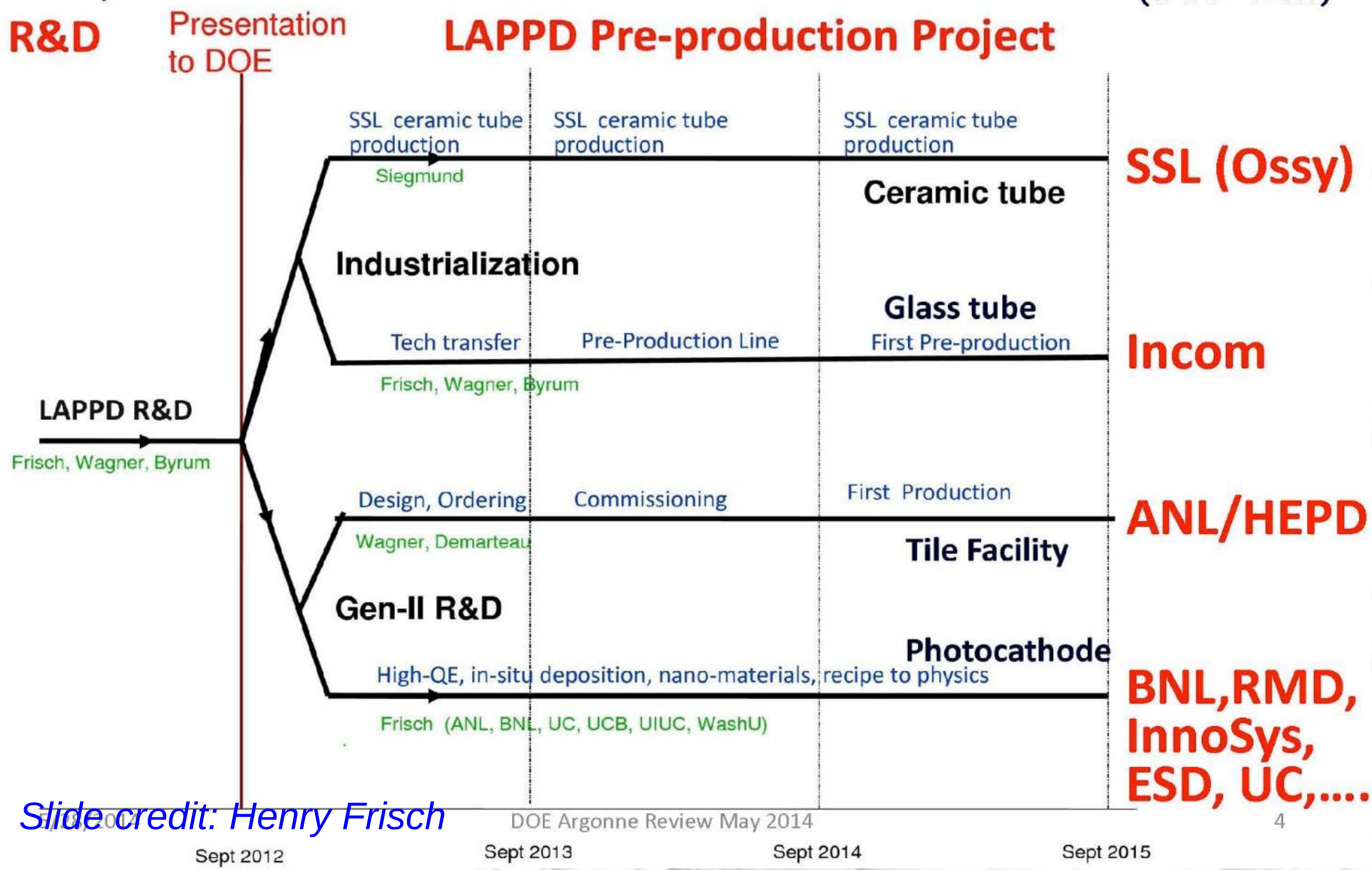
Putting first LAPPD tiles into real experimental settings for testing is the highest priority

Some examples of early adopters:

- ANNIE – Accelerator Neutrino Neutron Interactions Experiment
- Cherenkov/Scintillation light separation for particle ID
- Optical Time Projection Chamber
- TOF measurements at Fermilab Test Beam
- There are many more (lots of interest shown at the "Early Adopters Meeting" hosted by Incom Inc. in 2013)

The 2013 Transition from LAPPD to Production: The 4 Parallel Paths

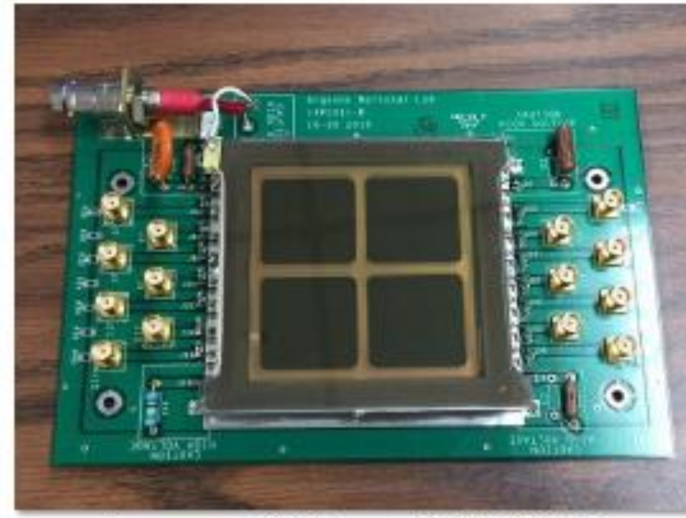
Dec 12, 2012 Presentation to DOE (a UC view)



Slide credit: Henry Frisch

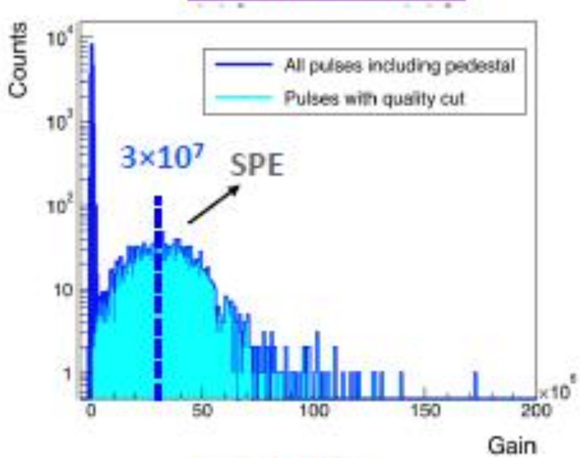
Argonne 6x6 cm^2 Photo-Detectors

- Argonne routinely producing 6X6 cm^2 functional detectors with K_2CsSb photocathode
- New IBD-1 design allows HV optimization, as biasing individual components possible
- In addition to assembly of photo-detectors, laser testing facility available and photocathode research ongoing.
- Performance:
  - Gain > 10^7
  - Quantum efficiency ~ 15%
  - Time resolution including the laser jitter: σ ~ 35 ps
  - Position resolution along anode strip: < 1 mm
  - Rate capability > 1 MHz/cm^2 for single photoelectrons



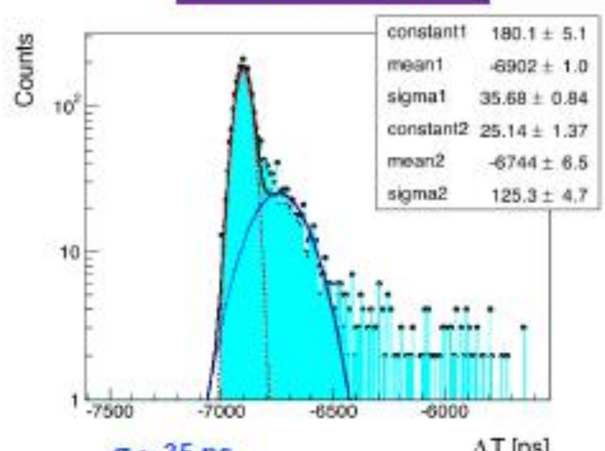
Argonne 6X6 cm MCP-PMT on custom readout board

Gain distribution



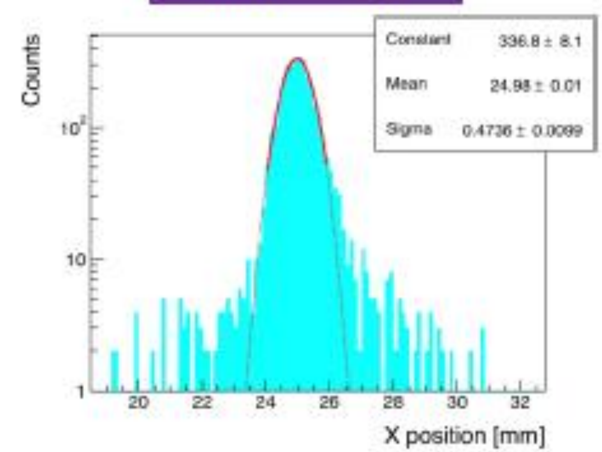
Gain > 10^7

Timing distribution

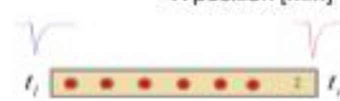


σ ~ 35 ps
for SPE, including
Laser jitter

Position resolution

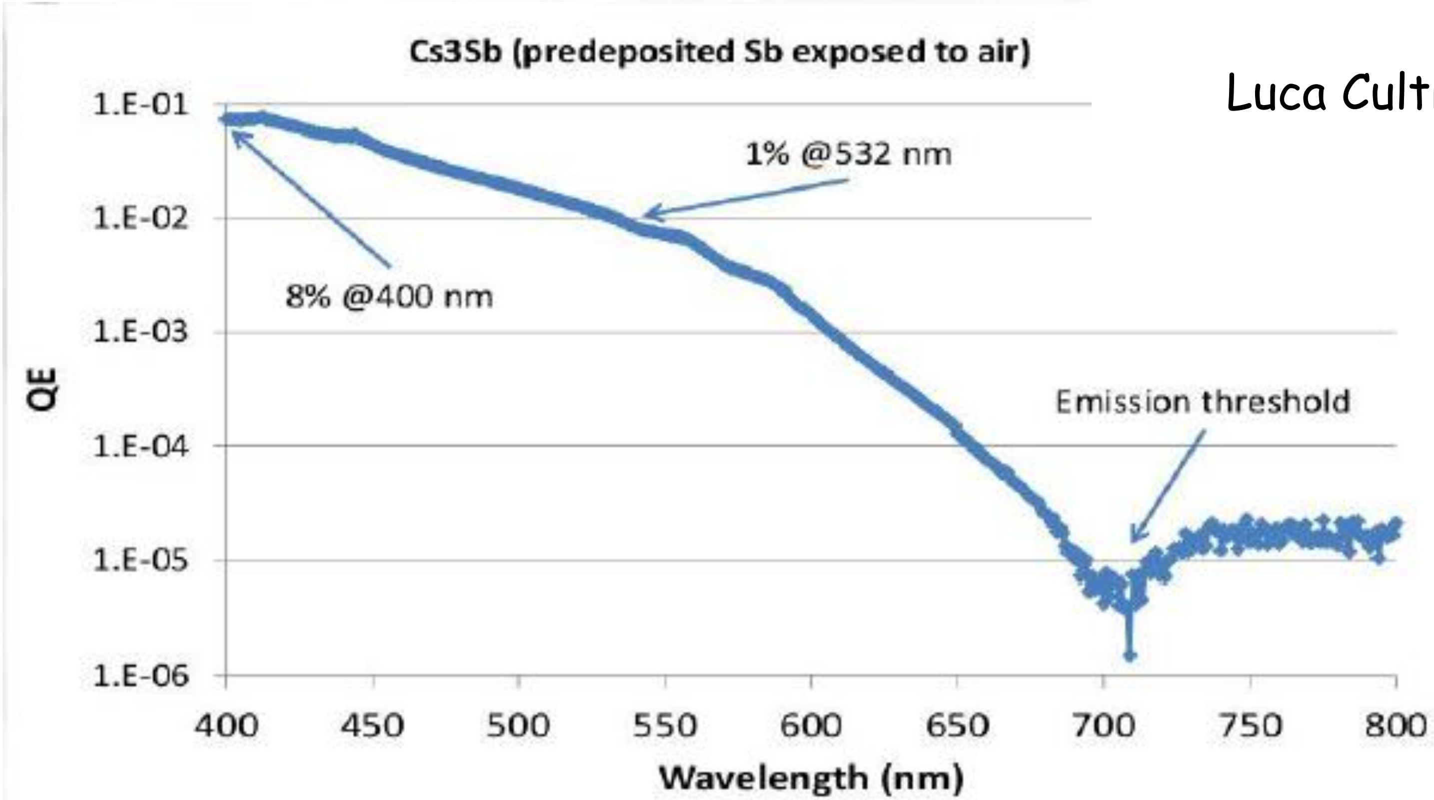


σ < 1 mm
for SPE



Slide courtesy of R. Darmapalan and R. Wagner, Argonne

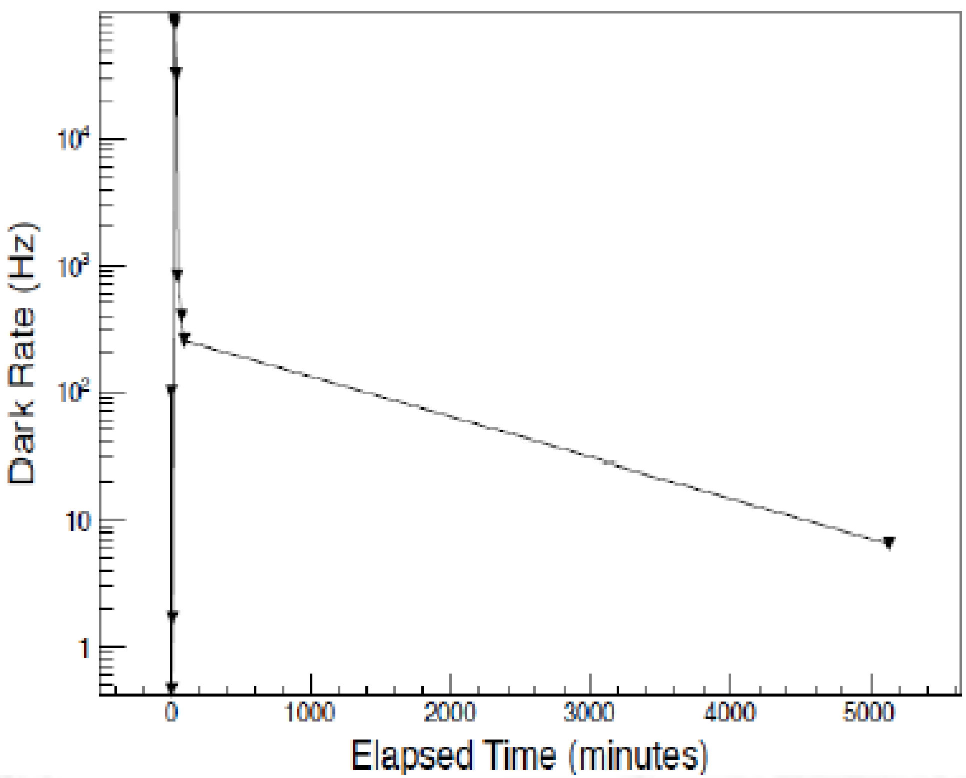
Can you make PC after Sb was exposed to air?

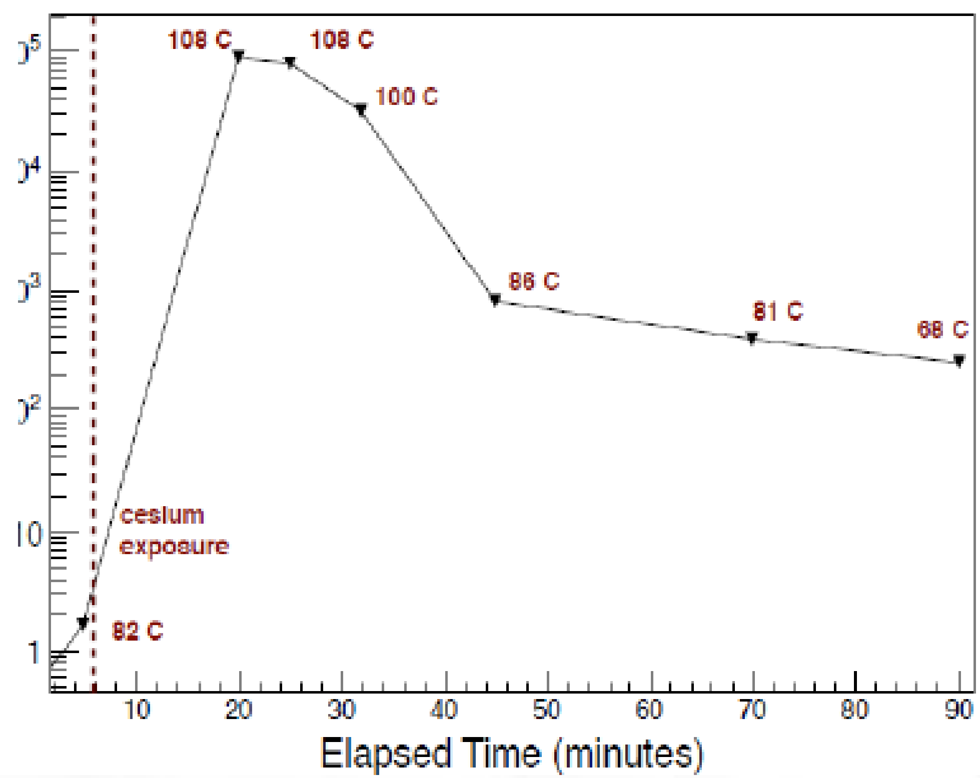


Luca Cultrera at Cornell

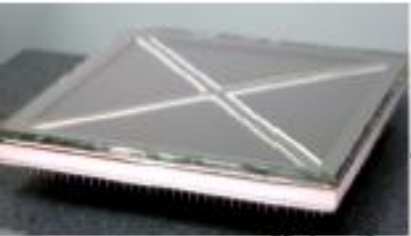
What about noise in the MCPs after Cs-ation?

Matt Wetstein



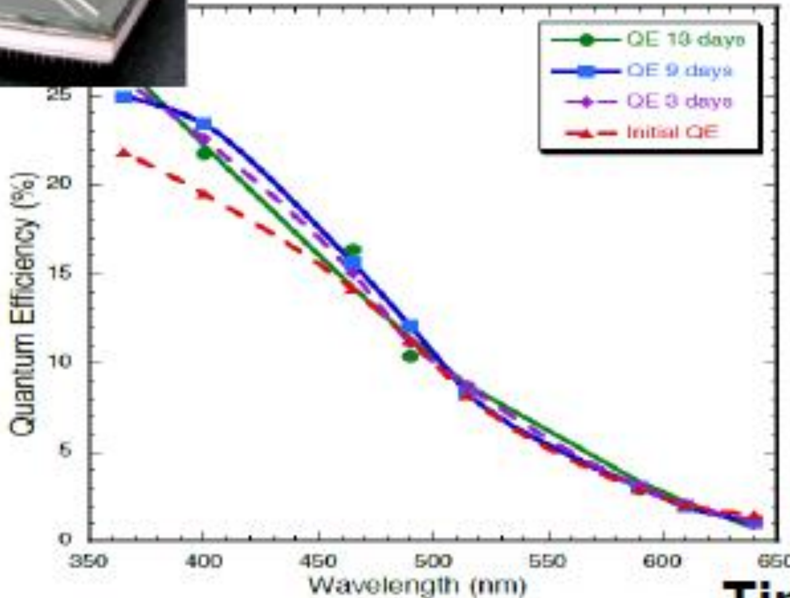


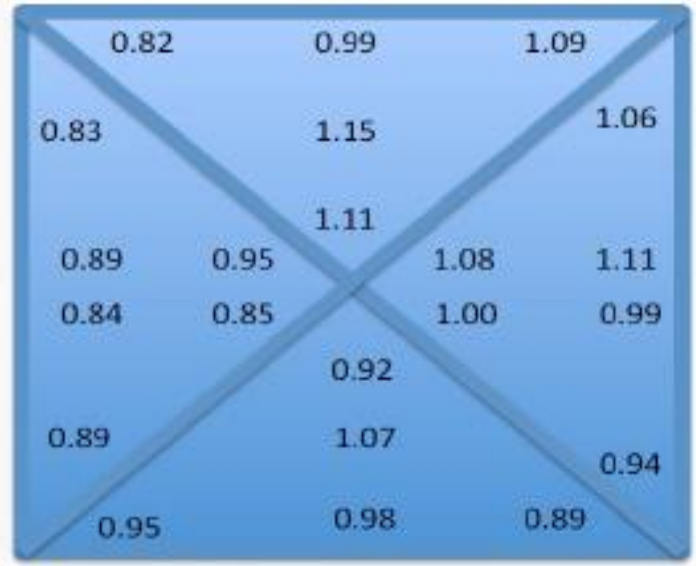
SSL Ceramic LAPPD Tile Results



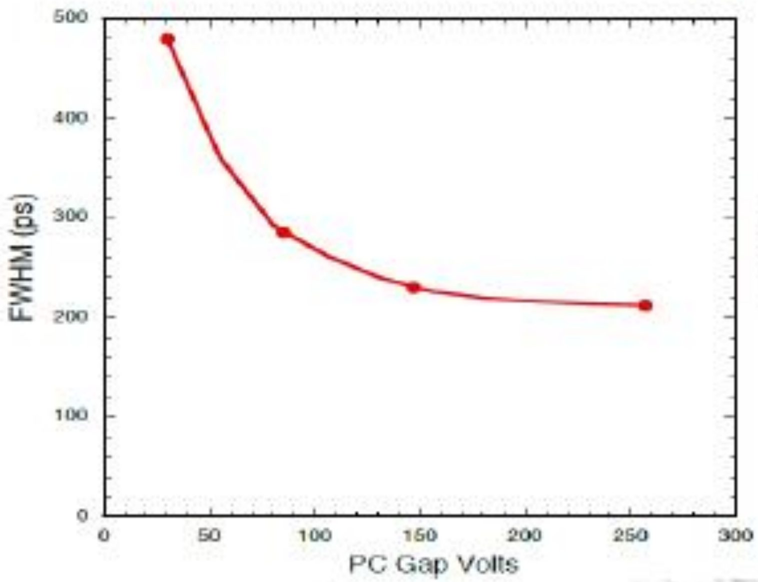
Measurements after full processing cycle inside the vacuum chamber

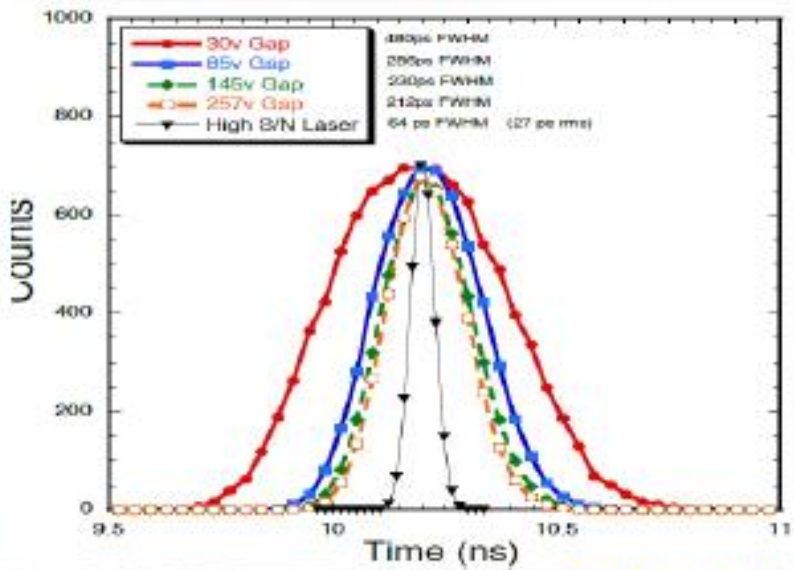
QE





Timing

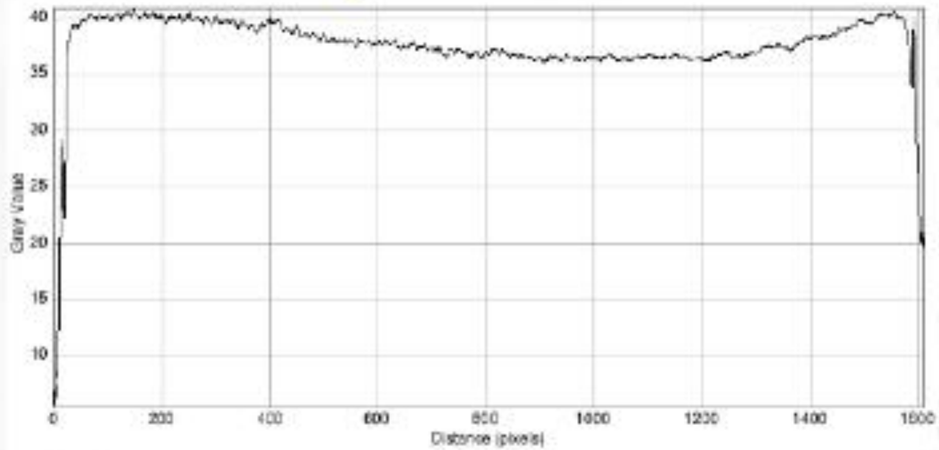


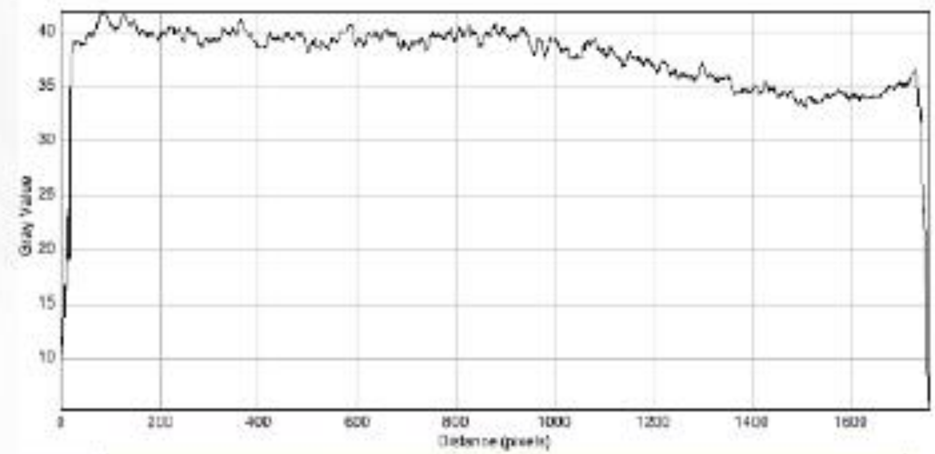


2014 JINST 9 C04002

Gain Uniformity

Gain map image for a pair of 20 µm pore, 60:1 L/D, ALD borosilicate MCPs, 950 V per MCP, 184 nm UV





Gain is uniform within ~15% across full 20 x 20 cm^2 area

O.H.W. Siegmund, N. Richner, G. Gunjala, J.B. McPhate, A.S. Tremsin, H.J. Frisch, J. Elam, A. Mane, R. Wagner, C.A. Craven, M.J. Minot, "Performance Characteristics of Atomic Layer Functionalized Microchannel Plates" Proc. SPIE 8859-34, in press (2013).

Noise <0.1 counts cm^{-2} s^{-1}

In-Situ Process Pre-requisite

Reliable hermetic seal over a 90-cm long perimeter

Indium Solder Flat Seal Recipe

Input:

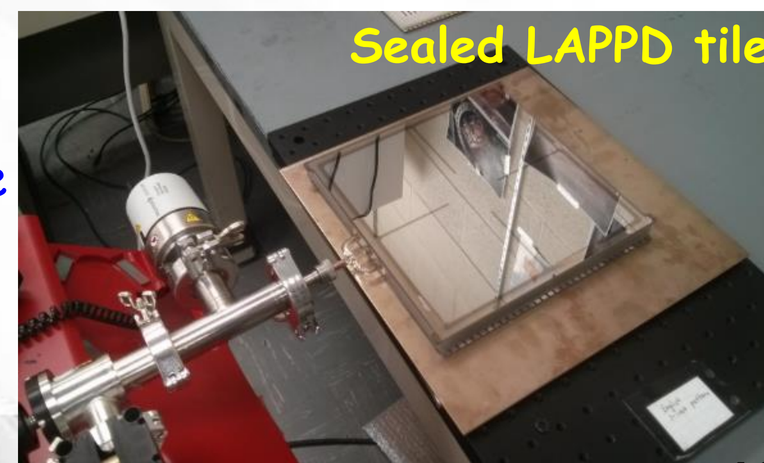
- Two glass parts with flat contact surfaces

Process:

- Coat 200 nm of NiCr and 200 nm of Cu on each contact surface (adapted from seals by O.Siegmund at SSL UC Berkeley)
- Make a sandwich with indium wire
- Bake in vacuum at 250-300C for 24hrs

Key features:

- A good compression over the entire perimeter is needed to compensate for non-flatness and to ensure a good contact
- In good seals indium penetrates through entire NiCr layer (Cu always "dissolves")



This recipe is now understood

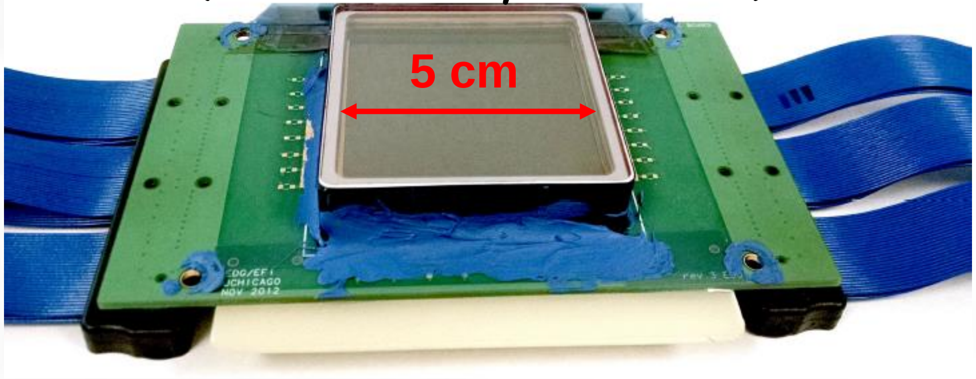
It works well over large perimeters

Metallization and compression are critical

Indium seal recipes exist for a long time

We adapted NiCr-Cu scheme
from O.Siegmund at SSL UC Berkeley

PLANACON™
(MCP-PMT by Photonis)



Why do we need another indium seal recipe?

Make larger photo-detectors
Our recipe scales well to large perimeter

Simplify the assembly process
Our recipe is compatible with PMT-like batch production

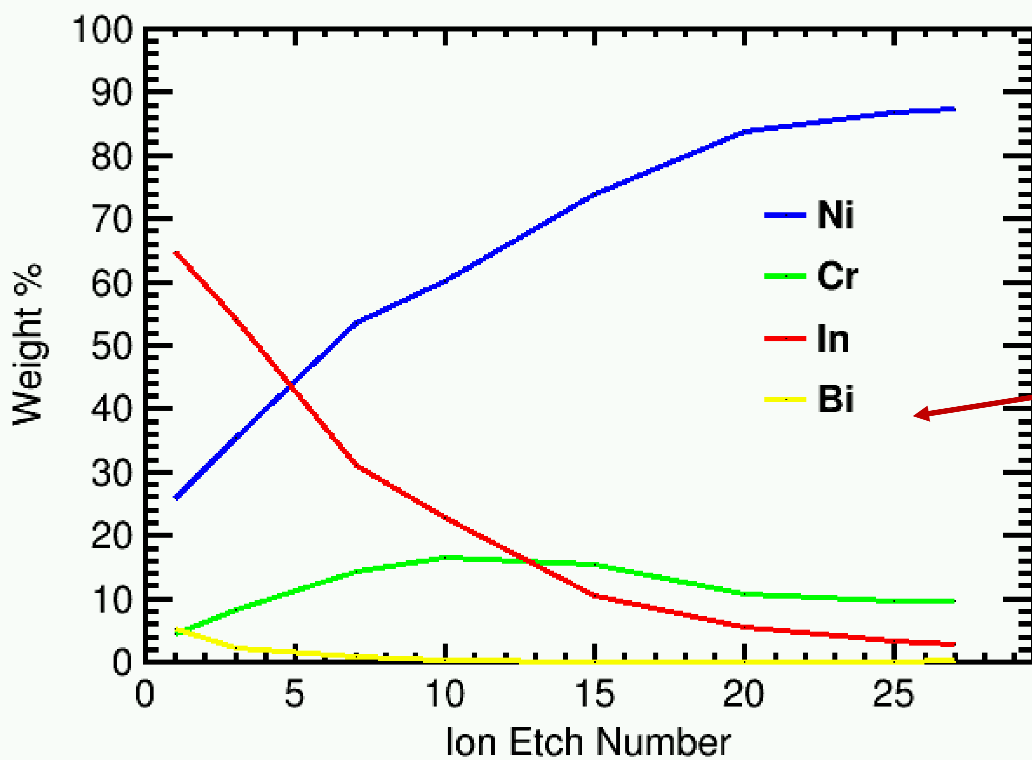
Metallurgy of the Seal

Moderate temperatures and short exposure time:

- A thin layer of copper quickly dissolves in molten indium
- Indium diffuses into the NiCr layer

Low melting InBi alloy allows to explore temperatures below melting of pure In (157C)

Depth profile XPS



Layer depth (uncalibrated)

Glass with NiCr-Cu metallization exposed to **InBi** at ~100C for <1hrs (it seals at these conditions)

InBi was scraped when still above melting (72C)

The ion etch number is a measure for the depth of each XPS run

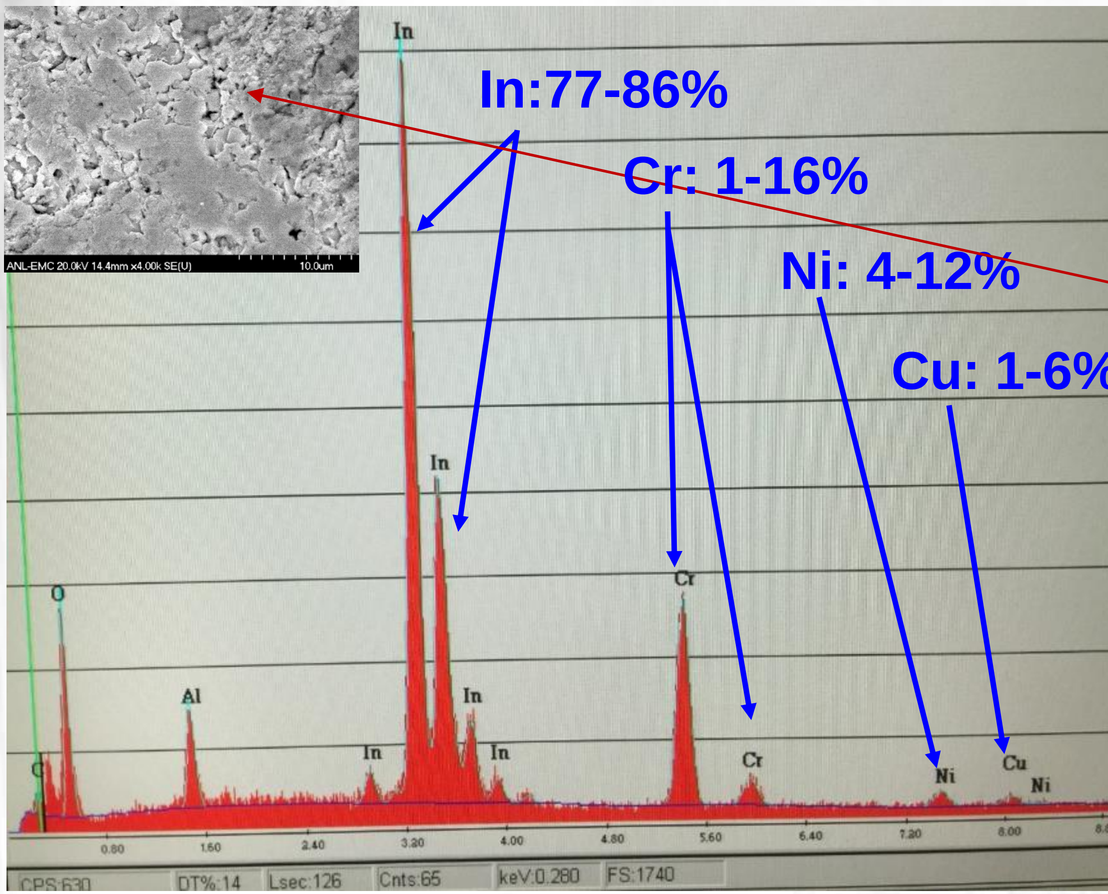
XPS access courtesy of J. Kurley and A. Filatov at UChicago

Metallurgy of the Seal

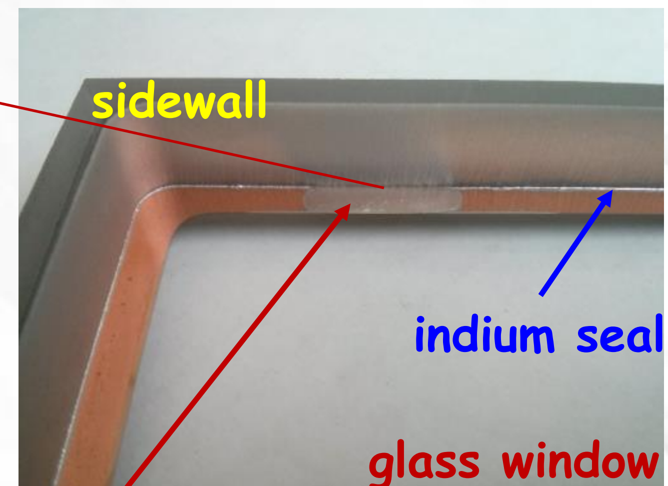
High temperatures and long exposure time

- Indium penetrates through entire NiCr layer

SEM and EDAX of the metal surface scraped at the interface



Glass with NiCr-Cu metallization bonded by **pure In** at ~250C for 2hrs (it seals at these conditions)



Cut and scrape at the metal-glass interface

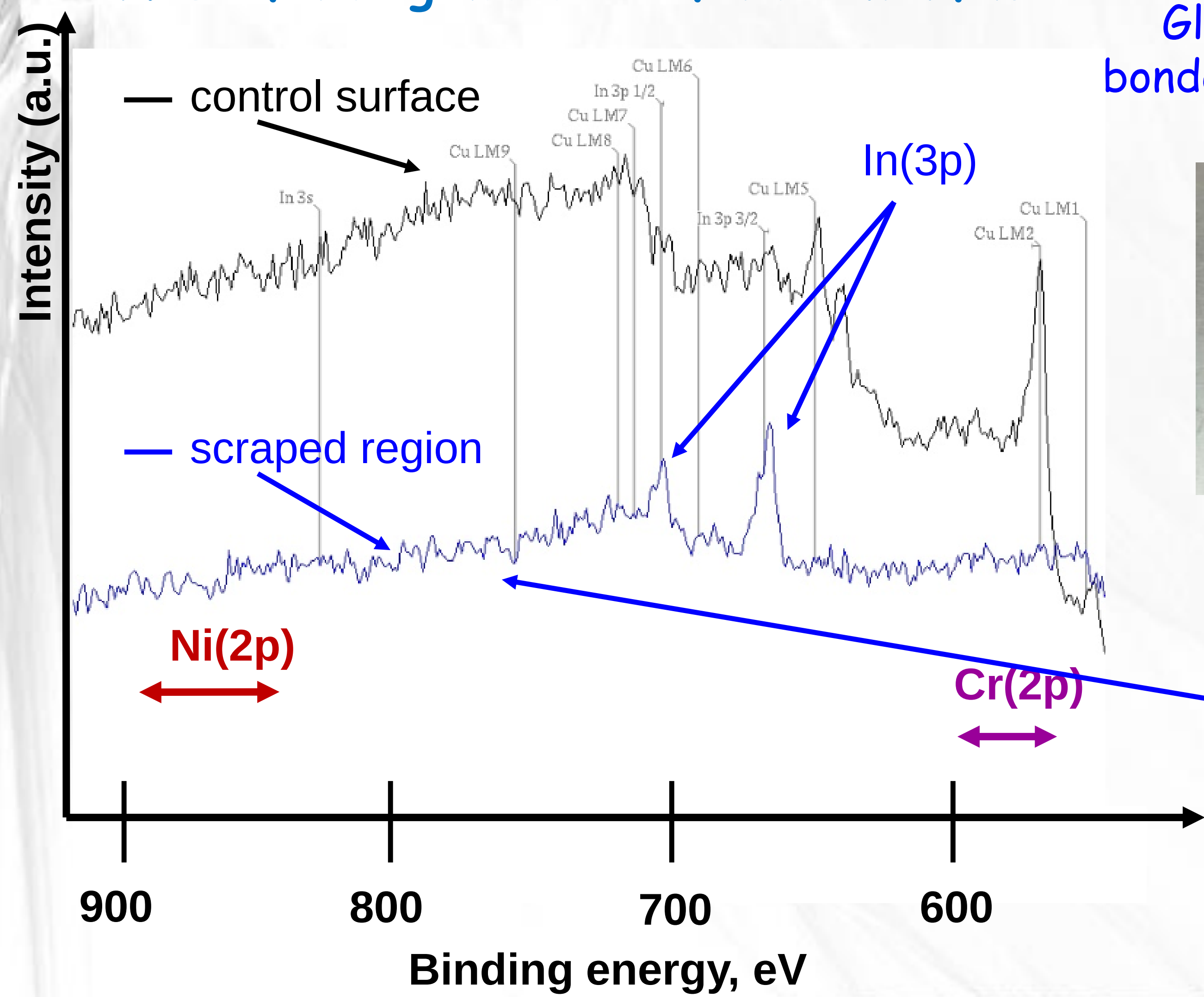
SEM/EDAX data courtesy of J. Elam at Argonne

Metallurgy of a Good Seal

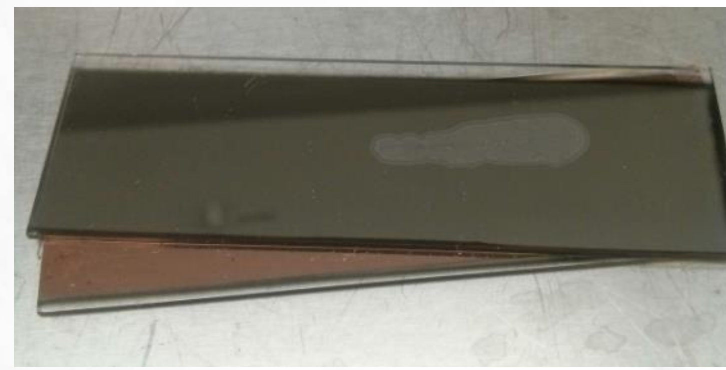
Higher temperatures and longer exposure time

- Indium penetrates through entire NiCr layer

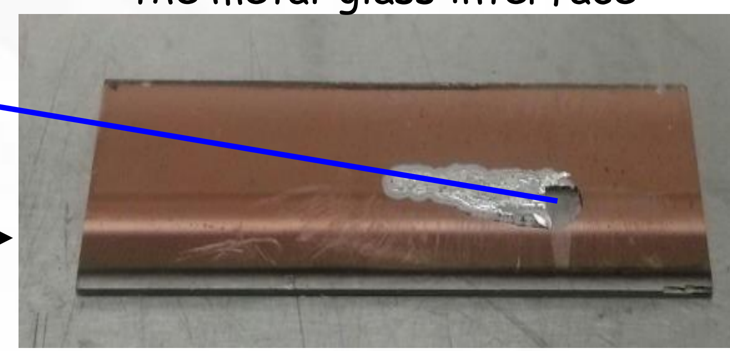
XPS of the glass side of the interface



Glass with NiCr-Cu metallization bonded by **pure In** at ~350C for 24hrs (it seals at these conditions)



Cut and scrape at the metal-glass interface



We now reliably seal at 250-300C for 12-24hrs

XPS data courtesy of A. Filatov at UChicago